FREE 2 eBOOKS 2 POSTERS & WALLPAPERS

WIN KID'S CAMERAS WORTH £190

NEW LOOK!

HOW IT WORKS

CLIMATE CHANGE: THEN & NOW

007's GADGETS

HOW JAMES BOND'S INCREDIBLE TOYS COMPARE WITH TODAY'S TECHNOLOGY

- SHAMPOO CHEMISTRY
- SOLAR PANEL TECH EXPLORED
- THE CRADLE OF CIVILISATION
- HOW GOOGLE EARTH WORKS

AR zone
SCAN TO WATCH THE NO TIME TO DIE TRAILER

FUTURE
ISSUE 156

EXPLORE THE AMAZON OF THE OCEAN

AMAZING ALTERNATIVE WAYS OF MAKING A BABY

COULD WE BUILD TOTAL RECALL?

WORLD'S DEADLIEST VOLCANIC ERUPTIONS

RAF RED ARROWS HAWK

1:72 A55002

The dual control BAE Hawk T. Mk.1 is the RAF's advanced trainer and has been used by the Red Arrows since 1979. The aircraft is essentially the same as those flown by RAF Advanced Training Students with the exception of the smoke generators and a slightly uprated engine giving a faster response time to changes of power setting.

Ideal for beginners or those with less display space, this set comes complete with 4 paints, glue and a paintbrush. A fantastic addition to your collection or a welcome gift for any time of the year.

Wingspan 131mm Length 155mm Pieces 240

Display stand included

Airfix.com
and all good retail stockists
YouTube

Start as you mean to finish
Humbrol™

Use your smartphone to find out more!

HORNBY HOBBIES
Official Product

WELCOME

Issue 156

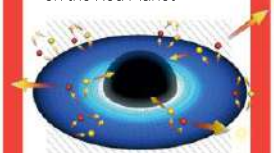
"The iconic weapon was put together from everyday objects"

Gadgets with license to thrill
PAGE 26

HIGHLIGHTS

30 GADGETMOBILE
Discover 007's famous Aston Martin DB5

66 MARTIAN LIVING
Inside a practical habitat on the Red Planet



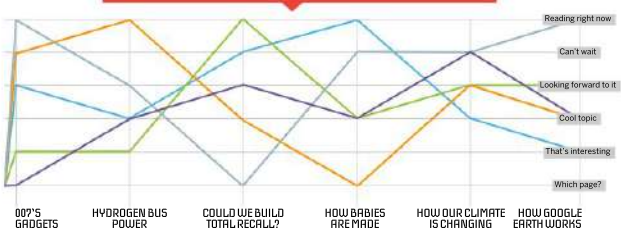
70 EVENT HORIZON
Putting Stephen Hawking's theory to the test

SUBSCRIBE NOW
GO TO PAGE 24 FOR GREAT DEALS

The image above is of one of the most famous gadgets in the James Bond canon: the Golden Gun. It was owned not by Bond himself, but by 007's nemesis Francisco Scaramanga in the 1974 film *The Man With The Golden Gun*. This titular weapon was assembled from four innocuous golden parts: a pen, a cigarette lighter, a cigarette case and a cufflink. It was a cool gadget in the film, though it was pure fiction, unlike Bond villain Auric Goldfinger's laser, which appeared in the 1964 film just a few years after the world's first industrial laser was built. Nearly 60 years and dozens of 007 films since, plenty of Bond tech that seemed pure fantasy at the time has been made reality. Turn to page 26 to find out more.

Ben Biggs

WHAT WE'RE ANTICIPATING



NIKOLE
PRODUCTION EDITOR

SCOTT
STAFF WRITER

AILSA
STAFF WRITER

CHARLES
RESEARCH EDITOR

DUNCAN
SENIOR ART EDITOR

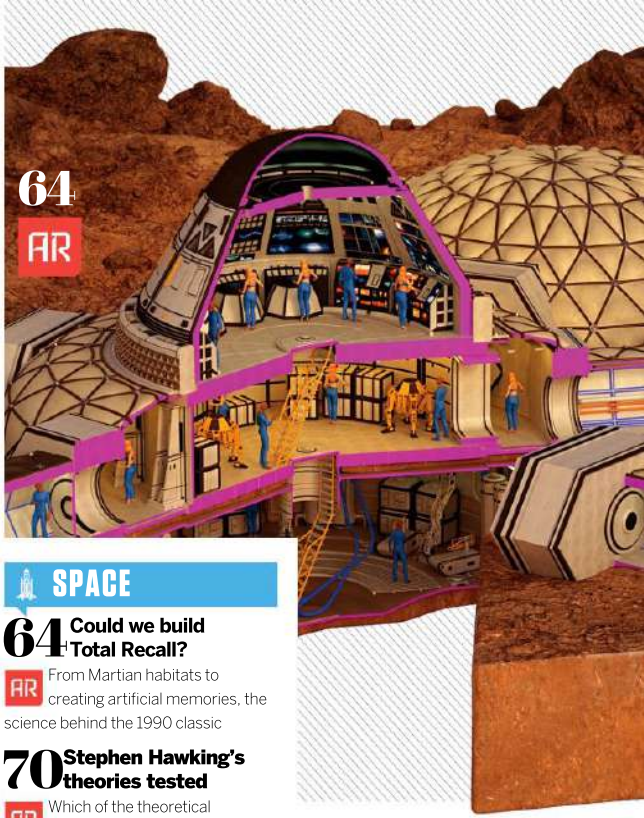
FOR EXCLUSIVE HIW NEWS AND OFFERS, SIGN UP TO OUR MAILING LIST HOWITWORKSDAILY.COM/NEWSLETTER

© Getty

FOLLOW US: HOW IT WORKS MAGAZINE @HOWITWORKSMAG @HOWITWORKS@FUTURENET.COM HOWITWORKSMAG

INSIDE

Issue 156



64 AR

SPECIAL

26 Gadgets with license to thrill
AR How much of James Bond's tech has become reality?

TECHNOLOGY

34 Inside Apple's newest iMac
We poke around inside the 24-inch M1 to see how it works

36 How solar panels generate energy
AR This cool silicon technology creates electricity from sunlight

38 Computer keyboard tech explained
Mechanical and membrane: what makes the modern typewriter work?

40 How does Google Earth work?
We explore the app that puts the world at your fingertips

TRANSPORT

42 Hydrogen bus power
See inside the world's first clean-energy double-decker bus

ENVIRONMENT

46 How our climate is changing
AR Eight worrying signs of the impact we have made on Earth

AR ZONE

Bring the pages to life

Scan the QR code with your device's camera or download a free QR code reader app. Many iPhone and Android devices include a QR reader

When you see the AR ZONE logo at the top of a page, use your phone to scan the QR code, which looks like this:

AR zone SCAN HERE

Hold your mobile device over the image and watch it come to life! Your device needs to be connected to the internet for this to work

52 10 deadly volcanic eruptions
How this awesome force of geology has helped shape our world

56 Amazon of the ocean
Why Asia's Coral Triangle is host to an abundance of marine life

HISTORY

58 What is the Ark of the Covenant?
Inside the fabled chest that is said to hold the Ten Commandments

60 Welcome to the cradle of civilisation
How Pakistan's ancient Indus Valley laid the groundwork for modern cities

SPACE

64 Could we build Total Recall?
AR From Martian habitats to creating artificial memories, the science behind the 1990 classic

70 Stephen Hawking's theories tested
AR Which of the theoretical physicist's big ideas turned out to be right?

SCIENCE

72 How babies are made
The incredible journey of human pregnancy and the many modern ways of making babies

78 Shampoo science
The common chemistry of today's hair-cleaning products

80 The wonder of water
How this vital substance has enabled life and changed our planet

REGULARS

06 Global eye
Science and tech news from around the world

22 Wish list
Get a new level of detail with the latest microscopes

62 Free eBooks and posters
Free **How It Works** digital specials and posters

84 Brain dump
Your questions answered

90 Book reviews

92 Brain gym
Give your brain a workout with our puzzle pages

94 How to...
Make glass invisible

96 Letters
Write to us and have your say

98 Fast facts

MEET THIS ISSUE'S EXPERTS

ANDY EXTANCE

Andy is a science writer. He previously worked in early stage drug discovery research, followed by a brief stint in silicone adhesive and rubber manufacturing.

DR ANDREW MAY

Andrew has a PhD in astrophysics and 30 years in public and private industry. He enjoys space writing and is the author of several books.

VICTORIA WILLIAMS

Evolutionary biologist and science writer Vicky is fascinated by the natural world and is happiest when she's in the outdoors.

JO ELPHICK

Jo is an academic lawyer and lecturer specialising in criminal law and forensics. She is also the author of a number of true crime books.

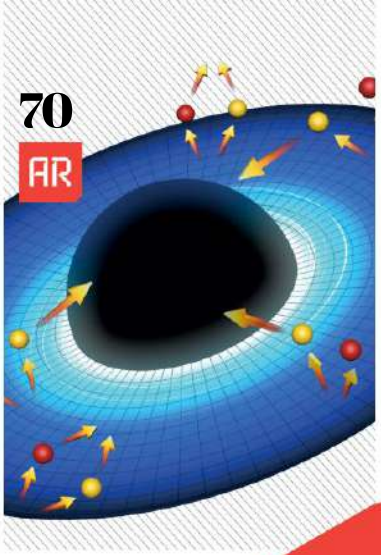
JAMES HORTON

James has a PhD in evolutionary biology and works primarily in microbiology. He's an experienced science journalist, having written for a number of science magazines.

MARK SMITH

A technology and multimedia specialist, Mark has written tech articles for leading online and print publications for many years.

78



70
AR

26
AR

WIN
TWO INSTANT-PRINT CAMERAS WORTH £190
PAGE 82

42

46
AR

56

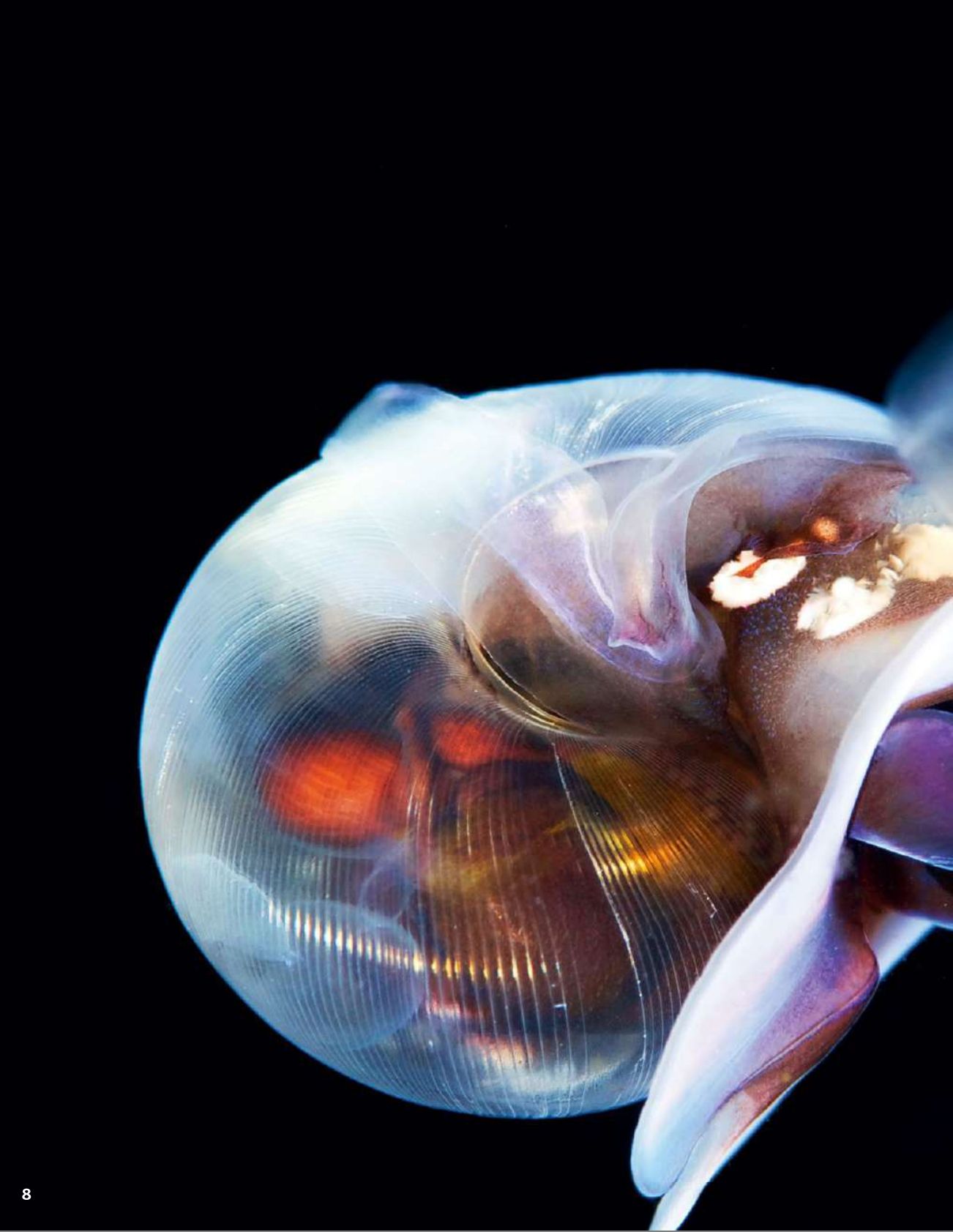
72

SUBSCRIBE NOW
GO TO PAGE 24 FOR GREAT DEALS

Inside the inner ear

These are inner ear sensory cells under a scanning electron microscope. The purple hair-like bundles of cells are called cilia. These sensory cells detect movement of the head using changes in the fluid they're immersed in: endolymph. As your head turns, it moves the fluid, altering the position of the cilia, which triggers the generation of an electrical pulse along the vestibular nerve to the brain.

© Getty



Butterflies below deck

Meet *Limacina helicina*, commonly known as the sea butterfly. Despite the name, these marine invertebrates are more closely related to snails than butterflies. Sea butterflies use muscular flat feet as 'wings' to propel themselves through the water. Their shells are made of calcium carbonate, which can be dissolved by more acidic ocean water, caused by increased atmospheric carbon dioxide.

© Getty

Curious caves

Crystal Cave in Bermuda was discovered in 1905 by two boys when a wayward cricket ball led them to the cave, adorned with stalactites. Stalactites form when water saturated with calcium bicarbonate from dissolved limestone seeps through cracks in a cave's ceiling. Calcium carbonate precipitates from the water and attaches onto the limestone roof, gradually forming elongated structures.

© Getty

Behind the space veil

Around 1,470 light years from Earth, in the constellation of Cygnus, is the Veil Nebula. This is one of the best known examples of a supernova remnant, whereby cosmic gas and dust released from an exploding star gathers to form huge clouds. The shock waves following the explosion shaped the remnant. It's estimated that the supernova event occurred around 10,000 years ago.

© ESA/Hubble & NASA, Z. Levay

ANIMALS

Chimps use 'hi' and 'bye' greetings

WORDS LAURA GEGGEL

Eastern chimpanzees (*Pan troglodytes schweinfurthii*) grooming each other

Chimps and bonobos signal 'hello' and 'goodbye' to one another when entering and exiting social encounters. Until now, this behaviour hasn't been documented outside of the human species. "Our findings show that two species of great apes habitually go through the same process and stages as humans when establishing, executing and terminating joint actions" of hi and bye, wrote researchers in a study of the primates.

The apes were also found to have a slew of nonverbal cues. This happens with humans, too. For instance, when people approach to interact, they often orient their bodies towards each other, look at each other and display the intention to touch, hug or kiss before talking. When leaving an interaction, people often turn their bodies away.

These behaviours amount to a 'joint commitment', which is partly a feeling of obligation that we feel towards one another, but also a process of setting up a mutual interaction and agreeing when to end it.

To determine whether chimpanzees and bonobos practise these behaviours, the researchers analysed 1,242 interactions of apes at zoos, discovering that these primates often communicate with one another, often with gestures that include gazing at and touching each other, holding hands or butting heads before and after encounters such as grooming or play. Of the two species, bonobos were the more polite, greeting each other more often than the chimps did.

When beginning a joint interaction, bonobos exchanged entry signals and mutual gazes in 90 per cent of cases, whereas chimps did so 69 per cent of the time. During departures, bonobos also outshined chimps, displaying exit behaviours 92 per cent of the time, whereas chimps showed it in 86 per cent of interactions.

The research team also investigated whether these behaviours changed when the apes interacted with close confidants. They found that the closer bonobos were with one another, the shorter the length of their entry and exit behaviours. "When you're interacting with a good friend, you're less likely to put in a lot of effort in communicating politely," said Raphaela Heesen, a postdoctoral researcher in the department of psychology at Durham University.

In contrast, the length of the chimps' entry and exit behaviours were "unaffected by social bond strength". This might be because in comparison with the hierarchical chimp society, bonobos are largely egalitarian, socially tolerant and emphasise friendships and alliances between females and mother-son relationships. As such, it makes sense that the bonobos' social relationships would have strong effects on their 'hellos' and 'goodbyes'.

Meanwhile, there was no significant effect of rank difference on the presence of entry or exit phases in either ape species. The findings suggest that perhaps a common ancestor of apes and humans practised similar behaviours. "Behaviour doesn't fossilise. You can't dig up bones to look at how behaviour has evolved. But you can study our closest living relatives: great apes like chimpanzees and bonobos," Heesen said. "Whether this type of communication is present in other species will also be interesting to study in the future."

The newly discovered island is extremely small and likely won't stick around for very long

PLANET EARTH

NEW ISLAND DISCOVERED CLOSE TO THE NORTH POLE

WORDS **YASEMIN SAPLAKOGLU**

In July, a group of scientists accidentally found themselves on a tiny island in northern Greenland made up of mounds of silt and gravel. "We were convinced that we were standing on Oodaaq island, which until then had been registered as the world's northernmost island," said expedition leader Morten Rasch, a senior consultant at the University of Copenhagen's Department of Geosciences and Natural Resource Management. However, using the GPS on their helicopter, Rasch's group confirmed that they were in fact on a new island, which they say is now the northernmost island on the planet.

The island is about 780 metres north of Oodaaq and is a mere 30 metres wide and 60 metres long, smaller than an American football field. The island stands three to four metres above sea level and is made up of small mounds of seabed mud and moraine, or soil and rock left behind by glaciers.

The small island, which is technically an expansion of the territory of Greenland and the Kingdom of Denmark, may have been formed by a powerful storm that, along with the sea, pushed these different materials from the seabed together. But the island might disappear soon.

Did you know? Svalbard is the most northern permanent settlement

STRANGE NEWS

Pi calculated to a record-breaking 62.8 trillion digits

WORDS **HARRY BAKER**

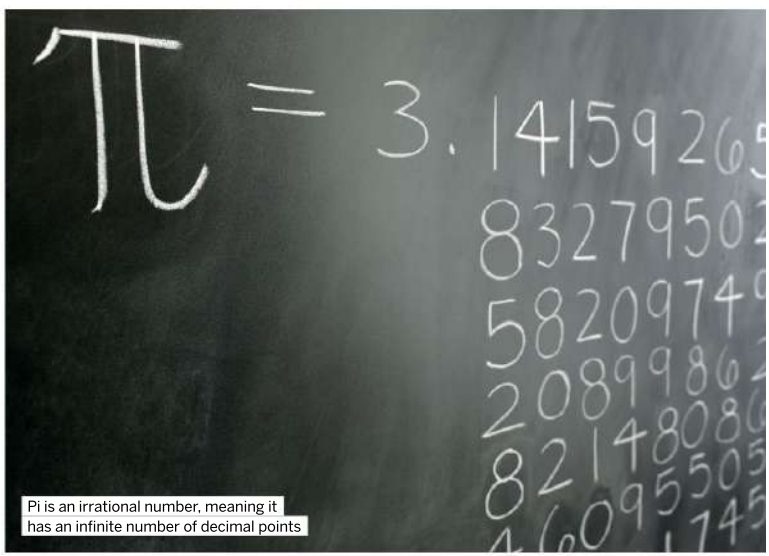
Researchers in Switzerland are set to break the record for the most precise value of the mathematical constant pi after using a supercomputer to calculate the famous number to its first 62.8 trillion decimal places. Pi is the ratio of a circle's circumference to its diameter. The name 'pi' comes from the 16th letter in the Greek alphabet and has been used by mathematicians to represent the constant since the early 18th century. The first ten digits of pi are 3.141592653, but the constant is what is known as an irrational number, meaning that it cannot be expressed as a common fraction and has an infinite number of decimal places.

On 5 August, researchers from the University of Applied Sciences of the Grisons in Switzerland announced that they had broken the record for the most accurate value of pi by more than 12 trillion decimal places using a computer at the Competence Centre for Data Analysis, Visualisation and Simulation (DAViS). The record attempt has yet to be officially confirmed by Guinness World Records, however.

"Breaking the record is just a side-effect of our work in preparing our high-performance computer infrastructure for work in research and development," said Thomas Keller, a computer scientist at the University of Applied Sciences of the Grisons. Knowing more digits of pi isn't particularly important for mathematics, but calculating the value of pi to high precision has long been used as a benchmark to test the processing power of computers. In 2019 a Google Cloud computing system calculated the constant's value to more than 31 trillion decimal places, and in 2020 Timothy Mullican of Huntsville, Alabama, founder of a nonprofit called North Alabama Charitable Computing, calculated 50 trillion decimal places using his own personal computer.

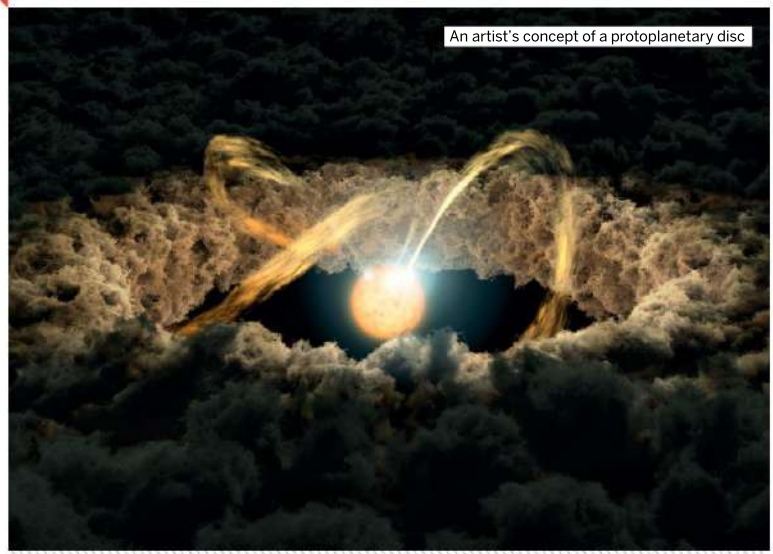
The DAViS team not only broke Mullican's record but also did so in roughly a third of the time, taking just 108 days and nine hours compared with Mullican's 303 days, even though they used the same algorithm to run the calculations. "Calculating to 62.8 trillion decimal places requires around 316 terabytes of RAM [around 324,500 gigabytes]," Keller said.

"Such a machine cannot be bought, to our knowledge, and if you could, it would be extremely expensive." The researchers plan to use the computer that performed the calculations to conduct computational fluid dynamics, deep learning and RNA analysis in the future, Keller said.



Pi is an irrational number, meaning it has an infinite number of decimal points

© Getty / Morten Rasch



An artist's concept of a protoplanetary disc

SPACE

Young star reveals what our Sun may have looked like

WORDS **CHARLES Q. CHOI**

Astronomers may have captured the best view yet of matter colliding with the surface of a young star, findings that could shed light on what the Sun looked like in its youth. Newborn stars are surrounded by a disc of gas and dust from which planets, asteroids, comets and moons are born. The star's magnetic field connects the star with this protoplanetary disc, "funnelling material from the disc onto the star," said Catherine Espaillat, an astrophysicist at Boston University.

In a recent study, Espaillat and her colleagues investigated the spot where a star's magnetic field deposits protoplanetary disc material onto a star. "This footprint is called the 'hotspot' since the material is very hot when it slams onto the surface of the star," she explained. The scientists focused on GM Aurigae, a star about the same mass as the Sun located about 420 light years away in the constellation of Auriga.

GM Aurigae is only about 2 million years old; in comparison, the Sun is about 4.6 billion years old. Previous work could not get a clear picture of the structure and dynamics of these hotspots. But in the new study, the researchers analysed GM Aurigae with multiple observatories: the Hubble, Swift and Transiting Exoplanet Survey Satellite (TESS) space telescopes, as well as the Small and Moderate Aperture Research Telescope System in Chile, the Lowell Discovery Telescope in Arizona, and the Las Cumbres Observatory global network of telescopes. "This is the first time such an extensive time-coordinated study has been done on a young star," Espaillat said.

The scientists found the visible light they detected from GM Aurigae peaked in brightness about a day after ultraviolet light. They suggested this happened because the source of the visible and ultraviolet light moved into and out of view as it rotated along with the star.

When combined with computer models of matter accreting onto stars, these findings suggest the hotspot varies in density from its centre to its rim on the star's surface. Areas of the hotspot with different densities have different temperatures and so emit different wavelengths of light.

"For the first time, we mapped the structure in this hotspot using observations and confirmed theoretical predictions," Espaillat said. "This result teaches us more about what our Sun looked like when it was young. Now our Sun has sunspots, dark areas where the temperature on the surface is cooler. When our Sun was young, it also had hotspots." Future research will analyse GM Aurigae and other stars to detect more details about these hotspots.

SPACE

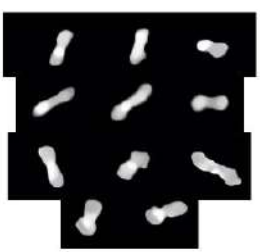
WEIRD 'DOG BONE' ASTEROID COULD BE COSMIC RUBBLE

WORDS **STEPHANIE PAPPAS**

Astronomers have fetched some cool new views of a dog-bone-shaped asteroid orbiting between Mars and Jupiter. Kleopatra, better known as the 'dog-bone asteroid' for its two-lobed shape, is about 167 miles long and has its own pair of moons. The new observations suggest that the asteroid is a loosely accumulated pile of rubble that probably formed from debris from a giant impact.

Scientists first discovered Kleopatra's dog-bone shape about two decades ago. The new observations of the asteroid were made between 2017 and 2019 by the European Southern Observatory's Very Large Telescope in Chile. As the asteroid rotated, the telescope captured it from different angles, enabling new calculations of the asteroid's length and volume.

Observations revealed the orbits of the asteroid's two moons. Along with the asteroid's length, this information allowed a team led by Miroslav Brož, an astronomer at Charles University in Prague, to calculate the mass of the asteroid, which at 2.97 quadrillion tonnes turned out to be 35 per cent lower than previously estimated. Its density, now estimated at 3.4 grams per cubic centimetre, is also lower than the previous estimate of 4.5 grams per cubic centimetre. The researchers also found the asteroid rotates very quickly, almost fast enough for it to start coming apart.



These 11 images of the asteroid Kleopatra were taken from different angles as the asteroid rotated between 2017 and 2019

ANIMALS

Five-metre-long sea monster ruled ancient Kansas ocean

WORDS MINDY WEISBERGER

About 80 million years ago, when dinosaurs still walked the Earth, a five-metre sea monster called a mosasaur cruised the ancient ocean that once covered western Kansas, snagging prey with its slender, tooth-lined snout. Palaeontologists discovered a fossil of this beast in the 1970s, but they had difficulty classifying it, so it ended up stored with other mosasaur specimens in the *Platecarpus* genus at Fort Hays State University's Sternberg Museum of Natural History (FHSM) in Kansas.

Recently, researchers revisited the enigmatic fossil – pieces of a skull, jaw and a few bones from behind the head – and found that the reptile didn't belong in the *Platecarpus* genus. Rather it was a close relative of a rare mosasaur species known from just one specimen. The newly described species, formerly known as specimen FHSM VP-5515 and now named *Ectenosaurus everhartorum*, is the second known species in the *Ectenosaurus* genus. The only other known species is *Ectenosaurus clidastoides*, which was described in 1967.

E. everhartorum's head was about 0.6 metres long, and like *E. clidastoides*, E. everhartorum had a snout that was narrow and elongated compared with those of other mosasaurs. "It's a kind of skinny snout for the agile, speedy snapping of fish, rather than biting into something hard like turtle shells," said Takuya Konishi, a vertebrate palaeontologist and assistant professor at the University of Cincinnati. The narrowness of the jaw and of a bone at the top of the head hinted that VP-5515 belonged in the *Ectenosaurus* genus, even though the fossil was about 500,000 to 1 million years younger than the *E. clidastoides* specimen, Konishi said.

But in some ways the skull wasn't *Ectenosaurus*-like at all. For example, it lacked a bony bump at the end of its snout. The snout on VP-5515 was also shorter than the one on *E. clidastoides*. "We knew it was a new species, but we didn't know if it was an *Ectenosaurus* or not," Konishi said. "To answer that puzzle, we were eventually able to find another feature where the jaw joint was, at the back end of the lower jaw." There the researchers detected a small notch that didn't appear in any mosasaur species – except one.

"That little depression turned out to be a newly discovered consistent feature for the genus *Ectenosaurus*," Konishi said. "You have this *Ectenosaurus* united by the little notch at the end of the lower jaw, but then it's consistently different at the level of the species from the generic type – that is to say the first species assigned to the genus."

One lingering question about *Ectenosaurus* is why this genus is so poorly represented among mosasaur fossils from western Kansas. To date, palaeontologists have uncovered more than 1,800 mosasaur specimens at the site of the former inland sea. But for now the entire *Ectenosaurus* genus is represented by just two fossils, one for each species. "That's very strange," said Konishi. "Why is it so rare for a mosasaur where you have hundreds of Platecarpus from the same locality? Does that mean they were living near the shore, or were they living farther south or farther north? We just don't know."

An illustration of a mosasaur (*Mosasaurus hoffmanni*) swimming in prehistoric waters

© Getty / NASA/JPL-Caltech

HEALTH

Lab-made mini brains grow their own 'eyes'

WORDS **YASEMIN SAPLAKOGLU**

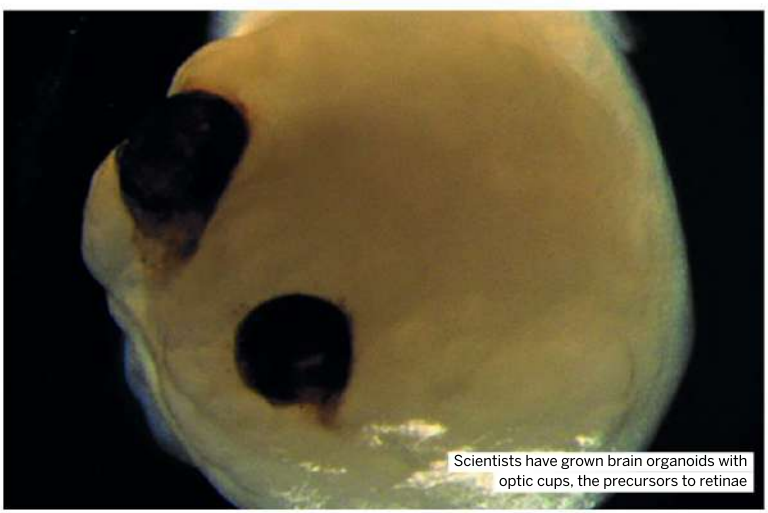
Organoids are miniature versions of organs that scientists can grow in the lab from stem cells, or cells that can mature into any type of cell in the body. Previously scientists have developed tiny beating hearts and tear ducts that could cry like a human's do. Scientists have even grown mini brains that produce brain waves like those of preterm babies. Now a group of scientists have grown mini brains that have something their real counterparts do not: a set of eye-like structures called 'optic cups' that give rise to the retina, the tissue that sits in the back of the eye and contains light-sensing cells.

In the human body, the retina sends signals to the brain via the optic nerve, allowing us to see images. "In the mammalian brain, nerve fibres of retinal ganglion cells reach out to connect with their brain targets, an aspect that has never before been shown in an in-vitro system," said Jay Gopalakrishnan, a researcher at University Hospital Düsseldorf. Previously researchers had grown optic cups individually in labs, but this is the first study that integrated optic cups into brain organoids.

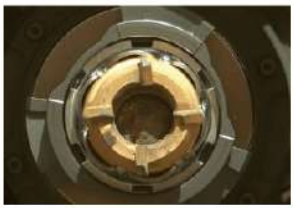
Did you know? Eyes start to develop in a foetus at seven weeks

Gopalakrishnan and his team adapted a technique they developed for turning stem cells into neural tissue. Once the stem cells had developed into mini brains, the organoids formed optic cups. The optic cups appeared as early as 30 days and matured within 50 days, a time frame similar to how the retina develops in a human embryo. In total, the researchers created 314 mini brains, and 72 per cent of them formed optic cups.

The organoids contained different types of retinal cells that formed active neuron networks that responded to light. The organoids also formed lens and corneal tissue. "Our work highlights the remarkable ability of brain organoids to generate primitive sensory structures that are light sensitive and harbour cell types similar to those found in the body," said Gopalakrishnan. The researchers now hope to figure out how to keep the optic cups viable for a long time and use them to research the mechanisms behind retinal disorders.



Scientists have grown brain organoids with optic cups, the precursors to retinae



A Martian rock core sample, about the width of a pencil, sits inside the Perseverance rover's collection tube

SPACE

'PERFECT' MARS ROCK SAMPLE DRILLED FROM THE RED PLANET

WORDS **BRANDON SPECKOR**

Following a failed first attempt, NASA's Perseverance rover has successfully drilled and captured a perfect rock core from the Red Planet. This takes scientists a step closer to their goal of someday returning the rock sample to Earth in order to study it for signs of ancient microbial life.

Perseverance made its latest drill attempt on 1 September after selecting a large, thick-looking rock that NASA researchers nicknamed 'Rochette'. The boulder sits on a ridge overlooking the nearby floor of Jezero crater, where it has endured the elements of Mars for potentially millions of years.

That endurance is exactly what the team was looking for; the rover's first attempt to collect a rock core several weeks ago ended in disappointment, as the rock sample proved too crumbly and slipped from the rover's grasp. But new images of the Rochette drilling operation show that this time around there were no surprising disappointments.

Perseverance will store the sample, which is about as thick as a pencil, in its belly for the duration of its mission exploring the dried-up ruins of ancient rivers in Jezero crater. But one day, perhaps a decade or so from now, Perseverance will place all of its samples onto the Martian floor, where another as-yet-unbuilt rover will come along to shepherd them to a small rocket that will bring them to Earth.

SPACE

Strange objects discovered past Neptune

WORDS STEPHANIE PAPPAS

A six-year search of space beyond the orbit of Neptune has netted 461 newly discovered objects. These objects include four that are more than 230 astronomical units (AU) from the Sun – an astronomical unit is the average distance from Earth to the Sun, which is about 93 million miles. These extraordinarily distant objects might shed light on Planet Nine, a theoretical body that might be hiding in deep space, its gravity affecting the orbits of some of the rocky objects at the Solar System's edge.

The new observations come courtesy of the Dark Energy Survey, an effort to map the universe's galactic structure and dark matter that began in 2013. Six years of observations from the Víctor M. Blanco Telescope at the Cerro Tololo Inter-American Observatory in Chile yielded a total of 817 confirmed new objects, 461 of which are now being described for the first time in a new paper.

The objects in the study are all at least 30 AU away, in a region of the Solar System that is almost unimaginably dark and lonely. More than 3,000 trans-Neptunian objects, or TNOs, have been identified in these icy reaches. They include dwarf planets such as Pluto and Eris, as well as small Kuiper Belt objects like Arrokoth, a rocky body visited by the New Horizons spacecraft in 2019. The Kuiper Belt is a region of icy objects orbiting between about 30 and 50 AU from the Sun.

Of the 461 objects described for the first time in the new paper, a few stand out. Nine are known as extreme trans-Neptunian objects, which have orbits that swing out at least 150 AU from the Sun. Four of those are very extreme, with orbital distances of 230 AU. At these distances, the objects are hardly affected by Neptune's gravity, but their strange orbits suggest an influence from outside the Solar System. Some researchers think that influence might be an elusive and undiscovered planet, dubbed Planet Nine. The newly discovered objects could thus help researchers hone in on the possible Planet Nine, or disprove its existence.

The researchers also found four new Neptune Trojans. Trojans are bodies that share the orbits of a planet or moon. In this case the objects share Neptune's orbit around the Sun. They also observed Comet Bernardinelli-Bernstein, named after the two lead authors of the paper, University of Pennsylvania cosmologist Gary Bernstein and University of Washington postdoctoral scholar Pedro Bernardinelli. The two researchers were the first to spot the comet in the Dark Energy Survey dataset. The Bernardinelli-Bernstein comet may be up to 100 miles wide. It hails from the Oort Cloud, another layer of icy objects even more distant than the Kuiper Belt.

At least 155 of the newly discovered objects are what astronomers call 'detached'. This means that they are far enough from Neptune that the large planet's gravity doesn't affect them much; instead they're mostly tied to the Solar System by the distant pull of the Sun. Detached objects, sometimes known as extended scattered disc objects, tend to have huge elliptical orbits.

The Dark Energy Survey wasn't meant as a search for trans-Neptunian objects. Its goals were to characterise the theoretical dark energy that affects the universe's accelerating expansion. Nevertheless, the data from the survey contains 20 per cent of all currently known TNOs, covering an eighth of the sky.

Many of the objects just discovered hail from the Kuiper Belt, a distant region of the Solar System full of icy bodies

© Getty / Elke Gabriel / NASA/JPL-Caltech/STScI/WMSS

A preserved cookiecutter shark on display during the Girls in Ocean Science Conference in California in 2016

ANIMALS

Cookiecutter sharks terrorise animals of all sizes

WORDS **PATRICK PESTER**

Cookiecutter sharks are known for ripping small, cookie-shaped chunks out of sharks and whales much larger than themselves, but a new study has found they actually terrorise animals of all sizes. The green-eyed, alienesque sharks look like sinister sock puppets made of pastry dough and can grow up to 50 centimetres long. These odd creatures use their pointed teeth to feed off great white sharks ten times their size and are even known to nibble chunks out of human flesh.

Scientists frequently observed cookiecutter markings on larger animals and thus assumed that's what the sharks primarily ate. But it turns out these sharks munch on animals at the bottom of the food chain as well, giving them a unique role in the ocean ecosystem, a new analysis of shark specimens has discovered.

"They feed on everything, from the biggest, toughest apex predators – like white sharks, orcas, everything you can imagine – down to the smallest little critters," said Aaron Carlisle, an assistant professor at the School of Marine Science and Policy at the University of Delaware. "There's not very many animals that do something quite like this."

Cookiecutter sharks live in tropical and subtropical waters and can inhabit depths of more than 1,500 metres. If humans see cookiecutter sharks, it's usually near the surface at night, when they come up to hunt larger prey in the upper ocean. The researchers tested the assumption that these sharks mainly eat larger animals in the upper ocean by studying 14 cookiecutter sharks caught around Hawaii by the Monterey Bay Aquarium. The sharks' stomachs were mostly empty of food, but the team figured out what the animals had been eating by looking at the chemical composition of their tissues. The team also checked for environmental DNA (eDNA), or the presence of DNA left behind even when there is no tissue to study.

"Environmental DNA is an increasingly popular and powerful tool that works under the idea that if an animal swims by in the ocean, it's going to be shedding DNA in the water," Carlisle said. "If you take a water sample and filter it out, you can extract the DNA of everything that's been in that water mass and identify what species were there. So we tried that on their stomach contents."

The researchers found that the cookiecutter sharks fed mostly on smaller species at lower depths, including crustaceans, squid and small fish. Some of these prey may be small enough for the sharks to swallow whole. In contrast, large animals from the upper ocean made up less than ten per cent of the sharks' diet. These findings shed light on the behaviour of this cryptic ocean creature, but the sample of sharks was small and from a limited geographic range, so it's unclear whether this feeding trend is the same throughout cookiecutter sharks' global range.

PLANET EARTH

RAIN FALLS ON GREENLAND'S SUMMIT FOR THE FIRST TIME

WORDS **BEN TURNER**

Rain has fallen on the summit of Greenland's ice sheet for the first time in recorded history, heightening concerns about the already-precarious condition of its ice. An unprecedented 6.3 billion tonnes of water pelted the ice sheet on 14 August, falling as rain and not snow for several hours. This was the third time temperatures at the summit had risen above freezing in less than a decade.

The rain occurred over two days and was also accompanied by the melting of up to 337,000 square miles of ice. "There is no previous report of rainfall at this location, which reaches 3,216 metres in elevation," said National Snow and Ice Data Center (NSIDC) researchers, adding that the amount of ice lost in one day was the same as the average ice lost across a typical week for the same time of year.

The rainfall, which is the heaviest since records began, is a sure indication that Greenland is warming at a rapid pace. "What is going on is not simply a warm decade or two in a wandering climate pattern. This is unprecedented," Ted Scambos, a scientist at the National Snow and Ice Data Center at the University of Colorado Boulder, said. "We are crossing thresholds not seen in millennia, and frankly this is not going to change until we adjust what we're doing to the air." Scientists attribute the cause of the rainfall to an anticyclone above the island.

An iceberg near Ilulissat, Greenland

The centre of the Milky Way, captured by the Spitzer Space Telescope's infrared cameras

Strange signal near Milky Way's centre has scientists stumped

WORDS BRANDON SPECKTOR

Astronomers have detected a strange, repeating radio signal near the centre of the Milky Way, and it's unlike any other energy signature ever studied. The energy source is extremely finicky, appearing bright in the radio spectrum for weeks at a time and then completely vanishing within a day. This behaviour doesn't quite fit the profile of any known type of celestial body, the researchers wrote in their study, and thus may represent "a new class of objects being discovered through radio imaging".

The radio source, known as ASKAP J173608.2-321635, was detected with the Australian Square Kilometre Array Pathfinder (ASKAP) radio telescope, situated in the remote Australian outback. In an ASKAP survey taken between April 2019 and August 2020, the strange signal appeared 13 times, never lasting in the sky for more than a few weeks. This radio source is highly variable, appearing and disappearing with no predictable schedule, and it doesn't seem to appear in any other radio telescope data prior to the ASKAP survey.

When the researchers tried to match the energy source with observations from other telescopes, including the Chandra X-ray Observatory and the Neil Gehrels Swift Observatory, as well as the Visible and Infrared Survey Telescope for Astronomy in Chile, which can pick up near-infrared wavelengths, the signal disappeared entirely.

With no apparent emissions in any other part of the electromagnetic spectrum, ASKAP J173608.2-321635 is a radio ghost that seems to defy explanation. Prior surveys have detected low-mass stars that periodically flare-up with radio energy, but those flaring stars typically have X-ray counterparts. That makes a stellar source unlikely here.

Dead stellar remnants, like pulsars and magnetars – two types of ultradense, collapsed stars – are also unlikely explanations. While pulsars can stream bright beams of radio light past Earth, they spin with predictable periodicity, usually sweeping their lights past our telescopes on a timescale of hours, not weeks. Magnetars, meanwhile, always include a powerful X-ray counterpart with each of their outbursts – again unlike ASKAP J173608.2-321635's behaviour.

The closest match is a mysterious class of object known as a galactic centre radio transient (GCRT), a rapidly glowing radio source that brightens and decays near the Milky Way's centre, usually over the course of a few hours. So far only three GCRTs have been confirmed, and all of them appear and disappear much more quickly than this new ASKAP object does.

However, the few known GCRTs do shine with a similar brightness as the mysterious signal, and their radio flare-ups are never accompanied by X-rays. If this new radio object is a GCRT, its properties push the boundaries of what astronomers thought GCRTs were capable of. Future radio surveys of the galactic centre should help clear up the mystery.

©Getty / NASA/JPL-Caltech/Harvard-Smithsonian CfA/Credit: Alamy

WISH LIST

The latest tech in MICROSCOPES

AMSCOPE 120 TO 1,200X KIDS BEGINNER MICROSCOPE STEM KIT

WWW.AMSCOPE.CO.UK / WWW.AMSCOPE.COM £35.99 / $52.99

For an entry-level microscope, the AmScope 120 to 1,200x 52-piece Kids Beginner Microscope STEM Kit really is the full package. The monocular viewing head is equipped with an LED light source and built-in colour filter wheel, providing up to 1,200x magnification with its rotating turret. Two AA batteries, which are included in the kit, are required.

But what makes this microscope so STEM-friendly? That would be all the tools that come along with it: the carrying case is packed with tweezers, prepared slides, collection vials, a petri dish, a replacement light bulb and more – there's a whopping 49 accessories in total. This excellent Amscope microscope is ready to use right out of the box, with no additional purchases required.

One unique feature of this microscope is the bundled shrimp hatchery experiment, which lets your youngster try their hand at the scientific method by observing the life cycle of these tiny aquatic creatures, taking notes from these observations and analysing the hatching process. From the instrument itself to the extra educational accessories, this is one of the best microscopes for kids you'll find on the market today.

OMANO JUNIORSCOPE

WWW.MICROSCOPE.COM $130 (APPROX. £94)

The Omano JuniorScope is a professional-looking 400x monocular microscope. Constructed from glass, plastic and metal components, it's heavier and more durable than many microscopes for kids. From examining rocks to marvelling at plant cells, young students can use this LED-powered microscope to magnify nature in crystal clarity. The JuniorScope comes with batteries, so it's ready to use right out of the box. The microscope is also bundled with a variety of scientific tools, such as slides, tweezers, a dropper and a petri dish. The microscope also comes with five experiment cards to help your child learn how to use their new research equipment.

MICROBRITE PLUS LED LIGHTED POCKET MICROSCOPE

WWW.CARSON.COM £22.99 / $17

Back garden exploration doesn't have to break the bank. The Carson MicroBrite Plus LED Lighted Pocket Microscope is an excellent case in point: this handheld stereo microscope is small enough to slip into any pocket, and the battery-powered LED light illuminates objects up to 120x in the palm of your hand. The aspheric lens system is surprisingly robust, resulting in bright, clear imagery all around.

For casual summertime beach excursions to winter woodland walks, this is a great complement to your next nature hike. Curious minds of all ages will enjoy the Carson MicroBrite Plus LED Lighted Pocket Microscope.

MY FIRST LAB DUO SCOPE MICROSCOPE

WWW.MYFIRSTLAB.COM

$79.99 (APPROX. £58)

The My First Lab Duo Scope Microscope has a lot to offer in the hands-on learning department. This 50-piece kit, like most other kits, comes with all sorts of scientific accessories, like blank slides, a plastic test tube and tweezers, in addition to an experiment guide and operating manual.

The lightweight design is durable enough for outdoor use, and the monocular eyepiece allows up to 400x magnification for whatever the next experiment entails. It functions as a compound and stereo microscope in one. This microscope is slightly on the pricey side, but it's a high-quality tool; the optics are made from glass, and the durable metal-and-plastic body is built to last. For those with a serious interest in science, this could be their first mini-lab.

OMAX MD82ES10 40 TO 2,000X DIGITAL LED COMPOUND MICROSCOPE

WWW.OMAXMICROSCOPE.COM **£259.99 /$334.99**

Is your child a scientific prodigy? Then maybe you should give their lab an upgrade. For secondary-school students who are ready to take their experiments to the next level, the OMAX MD82ES10 40 to 2,000x Digital LED Compound Microscope looks as professional as its name sounds. The swivelling binocular head has a built-in 1.3-megapixel USB camera that's compatible with both Mac and Windows, allowing the microscope to take pictures and video clips of various projects.

This digital microscope for kids offers eight LED-illuminated levels of magnification, from 40 to 2,000x. There are two coaxial knobs for coarse and fine focusing, and the mechanical stage is easy to adjust. There's also a sliding interpupillary distance adjustment, which means the microscope is customisable to virtually any face size.

NANCY B'S SCIENCE CLUB MICROSCOPE

WWW.LEARNINGRESOURCES.CO.UK / WWW.EDUCATIONALINSIGHTS.COM

£43 / $49.99

The best microscopes for kids aren't just standalone devices; they come bundled with all sorts of useful extras. Such is the case with Nancy B's Science Club Microscope, another colourful option that gets consistently high user reviews. Genuine scientific research is all about data collection, and this microscope gets that ball rolling with a 22-page activity journal.

Powered by two LED lights, the microscope itself can achieve an impressive range of 30 to 400x magnification, perfect for getting up close and personal with all the rocks, plants and bugs your back garden has to offer. Let the specimen collection begin!

© Amscope / Surepetcare / Myfirstlab / Gofetch / Educationalinsights

TIME LIMITED OFFER

SUBSCRIBE TODAY AND SAVE UP TO 60%

SIX-MONTH PRINT

SAVE 37%

SIX-MONTH DIGITAL

SAVE 45%

SIX-MONTH BUNDLE

SAVE 60%

WHY SUBSCRIBE?

- **Brilliant value – save money on the cover price**
- **You'll never miss an issue**
- **Delivery direct to you**

SUBSCRIBE NOW

www.magazinesdirect.com/hiw/know6

or call **0330 333 1113** and quote **BW30**

SIX-MONTH PRINT

£21.25 every six months

13 issues of **How It Works** in print over 12 months

SAVE 37%

SIX-MONTH BUNDLE

£23.75 every six months

13 issues of **How It Works** in print and digital over 12 months

SAVE 60%

SIX-MONTH DIGITAL

£14.25 every six months

13 issues of **How It Works** in digital

SAVE 45%

*Terms and conditions: Offer closes 30 November 2021. Offer open to new UK subscribers only. Pricing is guaranteed for the first 12 months and we will notify you in advance of any price changes. Please allow up to six weeks for delivery of your first subscription issue, or up to eight weeks overseas. Your gift will be delivered separately within 60 days after your first payment has cleared. Gifts only available to subscribers on the UK mainland. Gift not available with a digital subscription. The full subscription rate is for 12 months (13 issues) and includes postage and packaging. If the magazine ordered changes frequency per annum, we will honour the number of issues paid for, not the term of the subscription. For full terms and conditions, visit **www.magazinesdirect.com/terms**. For enquiries please call: +44 (0) 330 333 1113. Lines are open Monday to Friday 9am to 5pm UK time or e-mail: **help@magazinesdirect.com**. Calls to 0330 numbers will be charged at no more than a national landline call, and may be included in your phone provider's call bundle.

GADGETS WITH LICENCE TO THRILL

From space lasers and ships that can't be seen on radar to jet packs and submersible cars, how 007's tech has moved from fiction to fact

WORDS MARK SMITH

THE INVISIBLE SHIP

FROM: Tomorrow Never Dies

In his efforts to start a war between China and the UK so that he can make money from the resulting media coverage, dastardly media baron Elliot Carver uses a stealth ship, a vessel that's completely invisible to radar. But it looks uncannily like a ship that really existed. From 1985 to 2006, the US Navy developed the experimental Sea Shadow IX-529, which was designed to test stealth technology.

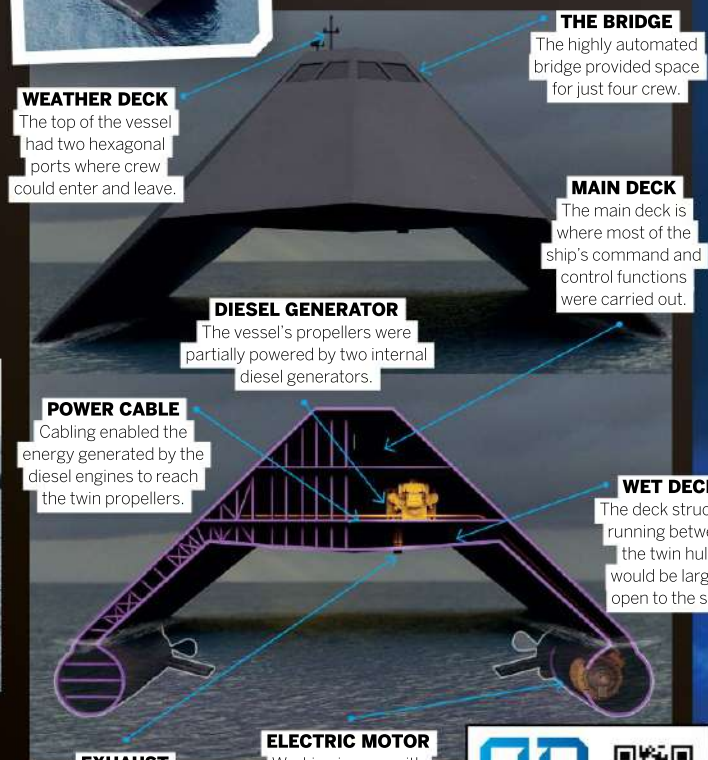
Both craft have a catamaran design and are made of black, radar-absorbing materials, much like the real-world stealth bomber and stealth fighter aircraft. Also known as the Sea Dolphin II, Carver's fictional craft had a 'sea drill', which it used to sink the HMS Devonshire in the film as a prelude to starting an armed conflict. It also had a range of missiles and a large crew complement. By contrast, the Sea Shadow only had a crew of four, and no weapons. It never saw action and was eventually sold for scrap!

The stealth craft Sea Shadow undergoes manoeuvres off the coast of San Francisco

Lockheed developed the sneaky sea vessel

INSIDE THE STEALTH CRAFT

Highly experimental, the Sea Shadow had a number of unusual design features



THE BRIDGE
The highly automated bridge provided space for just four crew.

WEATHER DECK
The top of the vessel had two hexagonal ports where crew could enter and leave.

MAIN DECK
The main deck is where most of the ship's command and control functions were carried out.

DIESEL GENERATOR
The vessel's propellers were partially powered by two internal diesel generators.

POWER CABLE
Cabling enabled the energy generated by the diesel engines to reach the twin propellers.

WET DECK
The deck structure running between the twin hulls would be largely open to the sea.

EXHAUST
The exhaust pumped out the potentially lethal exhaust fumes.

ELECTRIC MOTOR
Working in sync with the diesel engines, electric motors provided the power for the ship's propulsion.

AR zone SCAN HERE

Did you know?
Daniel Craig is younger than Bond itself

UNDERSEA PROBE

FROM: Tomorrow Never Dies

Carver's stealth ship launches the sea drill – or 'sea vac' – to sink a Royal Navy frigate in order to start a war. It's a wire-guided underwater drone with rotary cutters that can slice through a steel hull in just a matter of seconds. In the real world, autonomous underwater vehicles (AUVs) are being used for much less nefarious purposes, such as the Artemis, deployed in the search-and-rescue operation to try and track down the missing Malaysia Airlines Flight MH370. AUVs are also being increasingly used by the energy sector to scout oil and gas deposits, as well as for scientific research.

Drones like this sea drill are being used for a range of undersea operations

© Getty / AF Archive; UNITED ARTISTS; Alamy / Illustration by Nicholas Forder / Wiki Commons; US Navy

ROCKET MAN

FROM: Thunderball

In one of the most iconic Bond moments of the entire franchise, Sean Connery takes to the sky in a jet pack. The pack was actually a functioning Bell Rocket Belt that had been designed for the US army, but was rejected because of its short flying time of 21 to 22 seconds. Ever since, others have tried to come up with a more practical version. One of those is Gravity Industries, whose founder Richard Browning developed a jet suit reminiscent of the one used in the Bond film and, a few decades later, Marvel's *Iron Man* films. With more thruster jets, it's able to stay airborne longer than Bond's version – his Daedalus Flight Pack has a top speed of 85 miles per hour, can fly for about five minutes at up to 80 miles per hour and climb to 365 metres.

A NEW WAY TO FLY?

Richard Browning's jet suit could usher in a new era of flight

DIGITAL DISPLAY
The helmet displays all the flight information the pilot needs to control the suit.

THRUSTER PACK
A fifth thruster is fitted inside the backpack worn by the pilot.

METAL FRAME
A metal frame is used to secure the thruster and power pack to the wearer.

LIGHTWEIGHT FOOTWEAR
The boots are designed to be protective while not weighing the pilot down.

IRON MAN THRUSTERS
The suit has two miniature jet engines on each arm to allow for changes in direction and altitude.

The Browning jet suit is the latest take on an idea featured in a legendary Bond scene

DRIVING BENEATH THE WAVES

FROM: The Spy Who Loved Me

Nothing sums up the magic of a Bond film quite like driving a car into the ocean, with it carrying on the journey by turning into a submarine. Dubbed Wet Nellie, the production version was a submarine built specially for the film in the shape of a Lotus Esprit S1 sports car. In 2008, the Rinspeed sQuba became the first car to be able to travel underwater. Unlike Bond's Lotus, which was pressurised, allowing the driver to stay dry, sQuba is open to the water, with those inside having to don scuba gear. But with its ability to travel submerged, just like Bond's car, it's about as close to his Lotus submarine as it's possible to get.

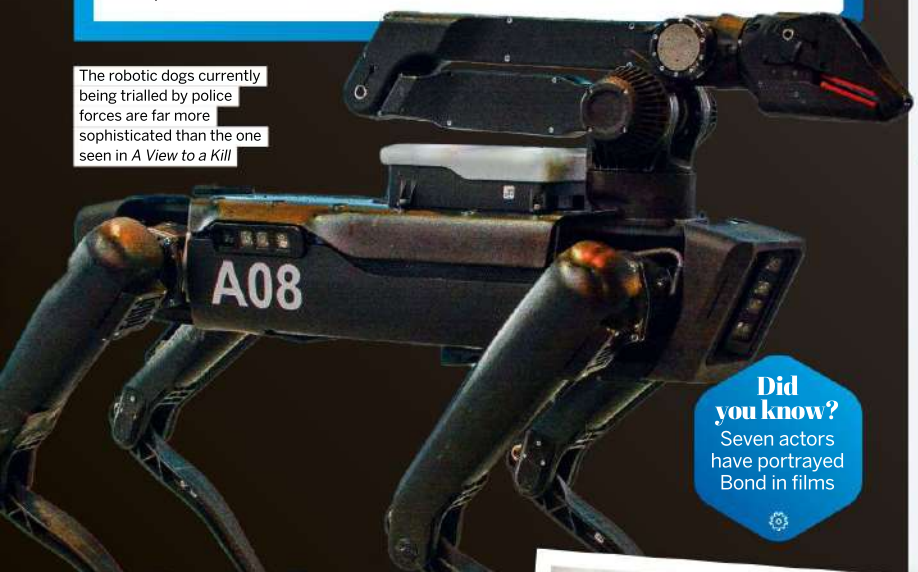
The sQuba car can dive beneath the waves, just like Bond's famous Lotus

A BRUSH WITH DANGER

FROM: License to Kill

One concoction that was guaranteed to remove plaque – along with the rest of your head – was Bond's 'Dentonite' toothpaste. The explosive putty was a creation conjured up by Q Branch, consisting of explosive paste mixed with regular toothpaste as a disguise, so Bond could slip it past any airport's – or henchman's – searches. Of course, we're not likely to find much of a market for exploding toothpaste, but using everyday items for deadly purposes is something real-life spies have attempted. In fact, one alleged plot had the CIA attempt to assassinate the leader of the Democratic Republic of Congo Patrice Lumumba with poisoned toothpaste in 1961.

It wasn't the first time something so innocuous was used as a weapon



The robotic dogs currently being trialled by police forces are far more sophisticated than the one seen in *A View to a Kill*

Did you know?
Seven actors have portrayed Bond in films

ROBOTIC CANINES

FROM: A View to a Kill

What better way to gather information on unsuspecting rivals than with a pet pooch that's wired for sound? In *A View to a Kill*, the Snooper is a remote-operated surveillance robot developed by Q Branch for gathering information.

Earlier this year, the New York Police Department started deploying its own robotic dog, dubbed the Digidog. Developed by Boston Dynamics, it's far more sophisticated than Bond's version. Whereas Bond's was remotely controlled by an operator and had wheels, Digidog has legs and can make its own decisions thanks to artificial intelligence.

After briefly being deployed in the Big Apple, it was quickly taken off the streets after backlash from the public. But other police departments in Massachusetts and Hawaii are also testing the digital dog device.

5 FACTS ABOUT BOND WATCHES AND WEAPONS

1 THE GOLDEN GUN
The iconic weapon used by flashy hitman Francisco Scaramanga comprises everyday objects: a cufflink (the trigger), a gas lighter (bullet chamber), a fountain pen (the barrel) and a cigarette case (the handle).

2 LASER WATCH
Bond wears an Omega Seamaster in *Goldeneye* which can fire a laser, which he uses to cut a hole in a train. German laser enthusiast Patrick Priebe built his own working version.

3 WRIST DART GUN
In *Moonraker*, Bond uses a dart gun strapped under his wrist like a watch, capable of firing small darts. Dart guns are widely used, particularly for tranquillising large animals.

4 THE EXPLODING OMEGA WATCH
In *Spectre*, Daniel Craig's Bond manages to get himself out of a tight spot by triggering his exploding Omega watch.

5 LASER GUN
The laser pistols used in *Moonraker* befit the film's setting in space. Chinese researchers have apparently developed an actual laser gun that can ignite a target from half a mile away.

© Getty / Gravity Industries / Alamy; Everett Collection Inc; ZUMA Press, Inc.; UNITED ARTISTS

ONE TOUGH AUTOMOBILE

FROM: Goldfinger

BOND'S MOST FAMOUS RIDE

Bond loves his motors, and nothing is as quintessentially 007 as the Aston Martin DB5

UNWELCOME GUESTS
An ejector seat could be activated to deter any backseat driving from passengers.

CONTROL PANEL
Bond's control panel featured a radar screen – today you'd most likely find a satnav.

PROTECTIVE COVER
Bond got extra cover when driving away from danger, with a shield that stopped bullets in their tracks.

SLICK DRIVING
The tail lights could eject hot oil onto the road, providing a slippery surface for any pursuing vehicles.

The US President's ride features similar technology to that used on Bond's Aston Martin

BULLETPROOF BODY
The body was bulletproof, much like many cars used by dignitaries and the military today.

Did you know?
'007' was the bus route used by Ian Fleming

DID YOU KNOW? Roger Moore suffered from hoplophobia – a fear of firearms – which led to some scenes having to be reshot

Without a doubt, the most memorable vehicle in the Bond franchise – and one of the most memorable in pop culture history – is this silver beauty. The model did exist in the real world, but unlike Bond's version, it didn't come with a range of advanced offensive and defensive weapons.

That's not to say in the real world vehicles don't have that type of technology when it comes to cars used by the military or to protect important people. The serving US president, for instance, travels in Cadillac One, an enhanced limousine dubbed 'the Beast' which features armour plating, foam around the fuel tank and bulletproof glass. Nowhere near as nimble as Bond's car – you're unlikely to see it undertake any hot pursuits – it weighs in at about nine tonnes and is reported to have tear gas grenade launchers, night-vision cameras and a built-in satellite phone.

WEAPONS DRAWER
Bond's guns and ammo were safely concealed away. Military and police vehicles have similar storage.

SECRET TELEPHONE
The door had a secret compartment for a phone. A mobile phone was pretty high-end tech back in the 1960s.

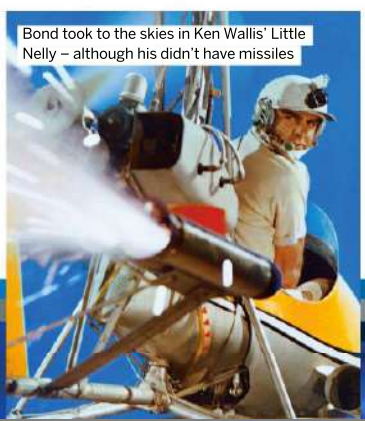
KEEP YOUR DISTANCE
The wheels had extendable tyre slashers so enemy vehicles couldn't get too close to our favourite super spy.

SPINNING PLATES
Revolving number plates helped Bond escape detection by the authorities and villains alike.

ARMED TO THE TEETH
The headlights hid two Browning machine guns to help get Bond out of tight spots.

THE MINI-AIRCRAFT FROM: You Only Live Twice

In *You Only Live Twice,* Bond takes to the skies in a special one-person aircraft to track down Ernst Stavro Blofeld's secret base. Dubbed 'Little Nellie', the aircraft is neither a plane nor a helicopter. It's actually an autogyro, which looks a bit like a small helicopter. But where it differs from a regular chopper is that it has no power to its rotor blades, which move via the momentum created by the aircraft's rear motor instead. Little Nellie was a cut-down version of the Wallis WA-116 Agile, developed in the early 1960s by former Royal Air Force Wing Commander Ken Wallis. The version we see on screen is the real one, although Bond's was heavily armed and was equipped with – among other things – rockets and flamethrowers. Bond's was also highly portable, being brought to him by Q Branch folded up in four cases.


Bond took to the skies in Ken Wallis' Little Nelly – although his didn't have missiles

© Getty / Alamy, UNITED ARTISTS, WENN Rights Ltd

GOING ORBITAL

FROM: Moonraker

Drax's space station was the stuff of science fiction when *Moonraker* was released in 1979, but since then we've seen the launch of Mir and the International Space Station (ISS). Mad billionaire industrialist Hugo Drax built the station in Earth orbit to house his master race. It was 260 metres wide and had artificial gravity, as well as a large hangar bay for space shuttles, and also had a powerful laser weapon. By contrast, the ISS is unarmed and isn't big enough to house spacecraft, instead having to dock with them. It also doesn't have gravity, with its crew having to train in a zero-gravity environment before they're posted up there. At 110 metres in diameter, it's also less than half the width of the fictional Bond station.

The station was destroyed in a laser gunfight

Drax's base was more than twice the size of the ISS and had its own artificial gravity

FUEL TANKS
A special fuel called monomethylhydrazine was stored for spaceflight once the disposable booster tank rockets were jettisoned after liftoff.

FORWARD REACTION CONTROL ENGINES
These jets were used for attitude control when the shuttle was manoeuvring, both in real life and in Bond.

STAR TRACKER
This system allowed a pilot to use the stars as points of navigation while in space.

FLIGHT DECK AND LIVING QUARTERS
This is where astronauts could work and pilot the shuttle without wearing spacesuits. Bond pilots Moonraker from here as he tries to stop Drax.

THERMAL PROTECTION SYSTEM
Moonraker and the shuttle were both reusable and designed for landing. Heat shields made of silica tiles protected the shuttle during the 1,650 degree Celsius heat of atmospheric re-entry.

CARGO BAY
Opening doors reveal an extensive cargo bay where equipment could be stored and transported into space. Moonraker could transport laser-wielding space marines; the shuttle was more likely to transport parts for the ISS.

DELTA WING
A double-delta-wing configuration helped achieve the most efficient flight during hypersonic speed, as well as providing a good lift-to-drag ratio during landing.

RUDDER AND SPEED BREAK
This allowed the shuttle to turn in-flight, and also provided deceleration during landing.

ENGINES
The shuttle had powerful main engines and smaller jets as part of its orbital manoeuvring system. Both Moonraker and the shuttle had to be launched into space on the back of a booster rocket.

SECRETS OF THE SHUTTLE

The Moonraker was based on NASA's Space Shuttle, which hadn't yet flown in 1979

DID YOU KNOW? *Goldfinger* was the first film ever to feature a laser beam. It also marked Bond's first time driving an Aston Martin

NO, MR BOND... I EXPECT YOU TO DIE

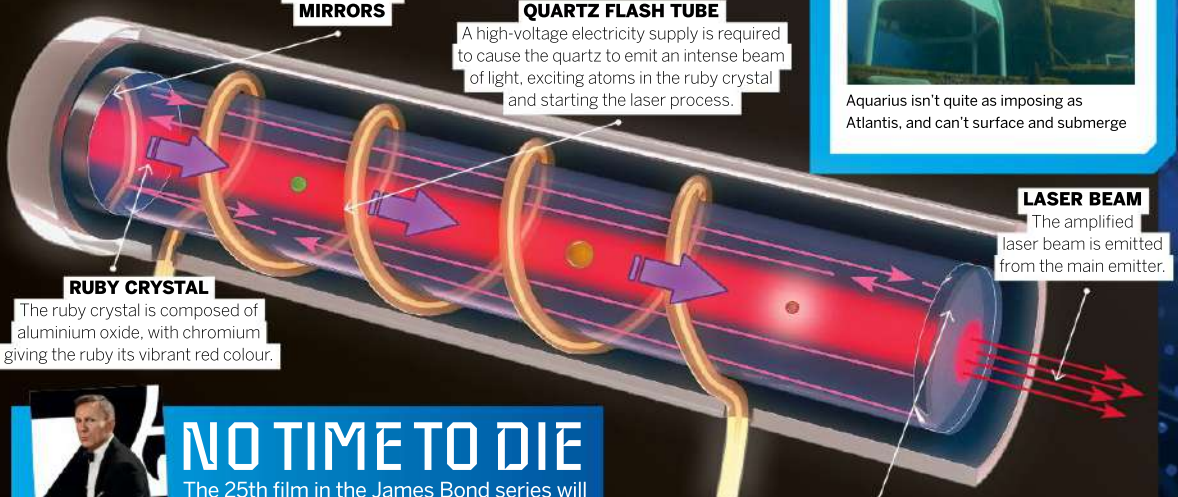
FROM: Goldfinger

Bond has found himself in innumerable scrapes over the years, but arguably none as harrowing as the prospect of being sliced in half by a laser beam – with the first parts to go being his privates. An industrial laser designed to slice through the vault doors of Fort Knox was the piece of tech which Goldfinger used to try and bring an end to 007's snooping around. In the real world, lasers have been deployed for industrial and military use for decades. From precision cutting in factories to now even being mounted on military vehicles, lasers are no longer the stuff of science fiction.

Laser cutters like the one in *Goldfinger* are widely used in industry

COMPONENTS OF A LASER

The first ruby laser meant such devices were no longer confined to science fiction


REFLECTIVE MIRRORS
QUARTZ FLASH TUBE
A high-voltage electricity supply is required to cause the quartz to emit an intense beam of light, exciting atoms in the ruby crystal and starting the laser process.
LASER BEAM
The amplified laser beam is emitted from the main emitter.
RUBY CRYSTAL
The ruby crystal is composed of aluminium oxide, with chromium giving the ruby its vibrant red colour.
REFLECTIVE MIRRORS
Mirrors at either end reflect light back and forth inside the ruby crystal, stimulating other excited chromium atoms to produce a powerful buildup, which produces the laser beam.

OCEANS OF TROUBLE

FROM: The Spy Who Loved Me

Atlantis was a base and research lab built by criminal mastermind Karl Stromberg. Located off the coast of Italy, it was a 200-metre, four-legged structure that could submerge. There are a number of undersea labs in the world, although none on the scale of Atlantis. Aquarius Reef Base sits 5.4 miles off the coast of Florida at a depth of 19 metres. At 37 square metres, it's much smaller than Stromberg's habitat, and it can't surface and submerge, but is instead fixed in position beneath the surface of the ocean. Whereas Atlantis was designed to be essentially a floating base and research lab, Aquarius is designed purely for research, with its depth allowing divers to travel short distances from inside to the ocean floor to carry out their work.

Aquarius isn't quite as imposing as Atlantis, and can't surface and submerge

NO TIME TO DIE

The 25th film in the James Bond series will be shown in cinemas worldwide from October onwards.

© Getty / Alamy, UNITED ARTISTS courtesy APL Archive, A.F. ARCHIVE and Courtesy Everett Collection

INSIDE APPLE'S NEW IMAC

Uncover the technology behind the 24-inch M1

WORDS **AILSA HARVEY**

The iMac M1 24-inch desktop computer was launched in May 2021. This new generation of iMac has a display diameter that's around seven centimetres more than its predecessor, but it's thinner than an iPhone 3GS. The iMac M1 allows for faster browsing and more impressive graphics. It features a sharp 4,480-by-2,520 pixel display. The brightness and colour tone of the screen automatically alter depending on the surrounding light, while an anti-reflective coating works to prevent screen glare.

As video communication increases in popularity, Apple has tried to incorporate camera improvements into this iMac model. This includes a camera with higher resolution and a sensor that can capture more light for clearer footage. In addition, the iMac M1 has three microphones that work together to isolate sound in one direction. This is called beamforming technology and means that the computer can better eliminate background noise during voice or video calls.

A consumer survey showed blue to be the most popular iMac M1 colour

BENEATH THE SCREEN

What components make Apple's thinnest iMac a cutting-edge device?

BATTERY BOARD
The computer has two thin complementary metal-oxide semiconductor (CMOS) batteries that charge when the iMac is plugged in.

INTERCONNECT BOARD
The interconnect board, which helps to connect computer components to the logic board, is wafer thin.

POWER BUTTON
The circular power button is found on the back of the monitor, on the bottom-left corner as you face it.

SPEAKERS
The integrated speakers consist of two small metal chambers. For their size they have a relatively large surface area, helping to maximise internal volume and sound.

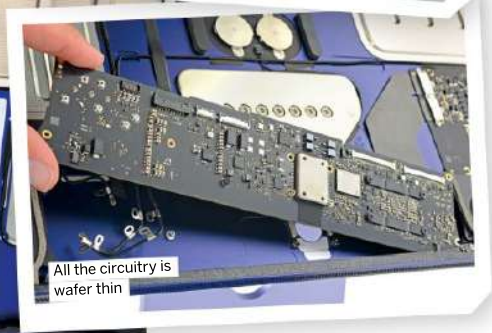
USB-C BOARDS
The USB-C ports are located at the back of the monitor. These can be used to charge the iMac and connect other devices.

SCREEN
The iMac is 11.5 millimetres wide, and the 24-inch display has 11.3 million pixels.

DID YOU KNOW? The iMac M1 produces over a billion colours on its display

HEADPHONE JACK
A modular headphone jack is located on the side of the computer, rather than the back. This is quicker and more convenient when plugging in headphones.

The iMac M1 screen is about twice as bright as the average computer's



All the circuitry is wafer thin

LOGIC BOARD
This is the main circuit board in the computer. It's similar in size to that of a MacBook Air.

The iMac M1 comes in green, yellow, orange, pink, purple, blue or silver and comes with a matching Magic Keyboard

MAGIC KEYBOARD

The keyboard that comes with the iMac M1 is a wireless device designed to make communication easier and your computer safer. At the top right of the keyboard is a Touch ID key, which reads your unique fingerprint to grant access to the computer and enable the purchasing of items using apps such as Apple Pay. One of the keyboard's settings allows the user to speak instead of typing, allowing for hands-free dictation. Another button changes the keyboard type from letters to emojis. The updated Magic Keyboard has new aesthetic features, including a variety of colours to match the monitors and curvier edges. The complete range of features of the keyboards only work when used with M1 models.

© iFixit.com / Alamy

HOW SOLAR PANELS WORK

From sunlight to light bulbs, this technology creates electricity from a natural resource

WORDS **AILSA HARVEY**

They can be found adorning roofs in a shiny, blue sheet, or lined up in rows as part of large energy farms. Solar panels were invented in 1954 but are becoming increasingly popular today as an environmentally friendly alternative to producing energy from fossil fuels.

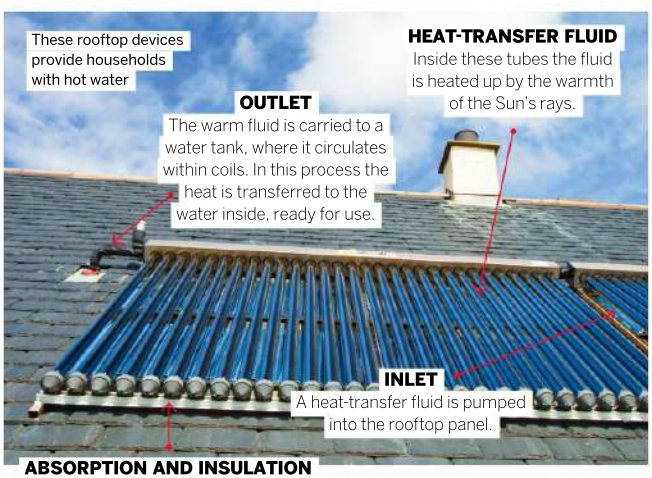
To create electricity these panels use the photons from sunlight to knock electrons free from atoms, producing a flow of electric current. Each panel consists of many smaller photovoltaic cells. These are usually made of two layers of silicon, a semiconducting material. The electricity produced in these cells is then converted into a usable form and carried in wires towards electrical appliances.

In 2020 there were around 500 solar farms in the UK alone

Around 900,000 houses in the UK have solar panels installed

PANEL TYPES

All solar panels work to make the Sun's energy usable, but different types convert this in different ways. While photovoltaic panels create electricity, solar thermal panels use the Sun's heat to warm up water by connecting to a building's boiler. After trapping the heat within the solar panels, a heat-transfer fluid – made of water and glycol – transports the heat energy between the two appliances.


These rooftop devices provide households with hot water
HEAT-TRANSFER FLUID
Inside these tubes the fluid is heated up by the warmth of the Sun's rays.
OUTLET
The warm fluid is carried to a water tank, where it circulates within coils. In this process the heat is transferred to the water inside, ready for use.
INLET
A heat-transfer fluid is pumped into the rooftop panel.
ABSORPTION AND INSULATION
A dark surface made of copper, aluminium or steel absorbs the heat, while an insulating layer below prevents it from escaping.

5 BENEFITS OF SOLAR PANELS

1 SUSTAINABLE ENERGY
Energy from fossil fuels is limited to the finite amount of resources on Earth, but solar energy can continue for as long as the Sun keeps shining.

2 MINIMAL MAINTENANCE
Solar panels should only require cleaning occasionally. As the technology has minimal moving parts, they can last for long periods without breaking down.

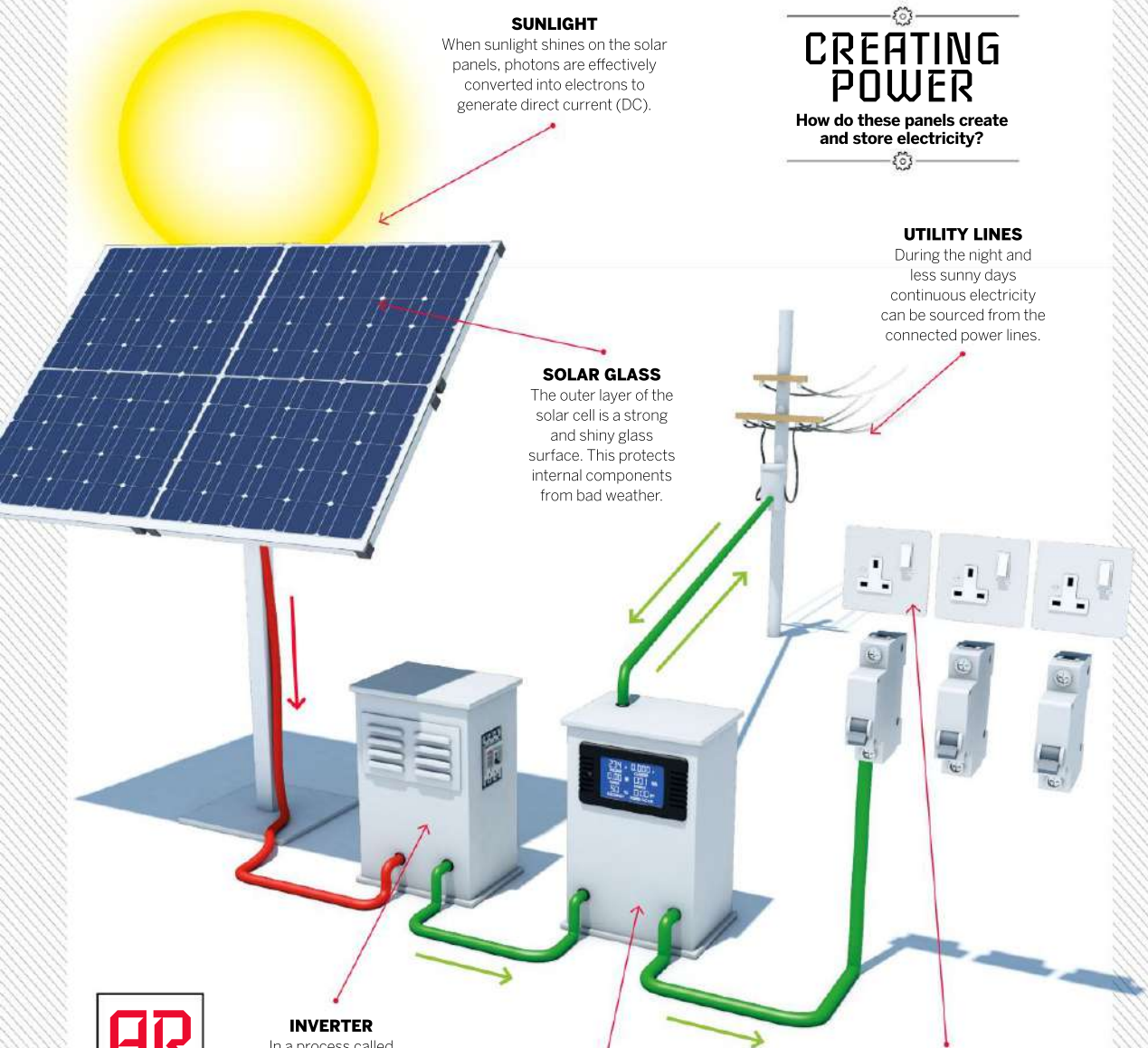
3 EXTRA ENERGY STORAGE
Any extra solar electricity generated that isn't used can be exported to the local electricity company to be used later.

4 OFF THE GRID
For extremely remote locations without access to electrical grids, solar panels are a useful solution. As long as there is sunlight, electricity can be produced right there at the site.

5 REDUCED EMISSIONS
Solar panels produce energy without releasing as many harmful emissions. The average solar panel will save over 900 kilograms of carbon dioxide from being released each year.

CREATING POWER

How do these panels create and store electricity?



SUNLIGHT
When sunlight shines on the solar panels, photons are effectively converted into electrons to generate direct current (DC).

SOLAR GLASS
The outer layer of the solar cell is a strong and shiny glass surface. This protects internal components from bad weather.

UTILITY LINES
During the night and less sunny days continuous electricity can be sourced from the connected power lines.

INVERTER
In a process called 'conditioning', the DC is turned into an alternating current (AC) by the inverter.

ELECTRIC METER
The amount of electricity stored is recorded by the meter. Any excess energy that won't be used immediately can be stored in batteries or sent to an electricity company.

ELECTRICITY USAGE
When electricity is turned on it flows through wires within the walls of the house, towards plug sockets, to power appliances.

AR zone

SCAN HERE

© Alamy / Getty / Illustration by Adrian Mann

COMPUTER KEYBOARD TECH EXPLAINED

What makes this modern typewriter work?

WORDS **SCOTT DUTFIELD**

Keyboards come built into laptops

Today's keyboards have evolved massively from the first mechanical typewriter, created and patented by Christopher Latham Sholes in 1868. The piano-like typewriter was very different to modern devices and was operated by a series of keys that, when pressed, lifted a lever to stamp the corresponding letter through an inked ribbon onto a roll of paper. In 1873 E. Remington and Sons began production of Sholes' invention, and the journey to modern-day computer keyboards began.

Now, more than 150 years later, the humble typewriter has been given a modern makeover in the form of computer keyboards. Rather than lifting levers, the keys on a computer keyboard work by completing an electrical circuit, in a similar way to how a light switch works. Within a keyboard is a matrix of circuits that carry an electrical current. The keys on the surface of the board are positioned over the tops of switches; when pressed, these close the switch and allow an electrical current to pass through. A microprocessor in the board recognises which switch has been closed and translates that into the corresponding key using a reference character map.

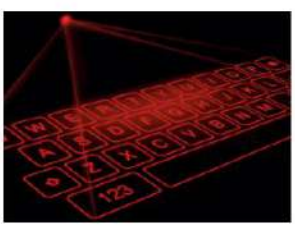
There are two main types of computer keyboards: mechanical and membrane keyboards. Mechanical keyboards use physical switches that are placed beneath the keys. When these keys are pressed it allows two points in the circuit to meet, passing the electrical current. A membrane keyboard, however, uses a series of pressure pads that are separated by a layer of electrically conductive and non-conductive materials. When a key is pressed the conductive layers connect, closing the switch and completing the circuit. A processor then receives a signal about which switch and corresponding key has been pressed, displaying it on a computer screen.

Did you know?
A common PC keyboard has 140 keys

LASER LETTERS

In 1992, IBM patented the first optical virtual keyboard. The design uses a laser to project a keyboard onto any flat surface. The user can simply touch a letter on the surface and it will appear on a computer screen.

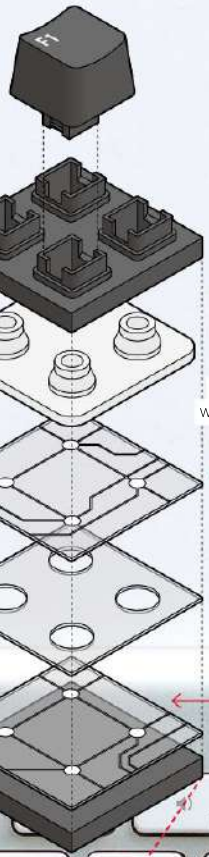
These laser alternatives emit a plane of invisible infrared light at the device's base. When a finger passes through the infrared plane, a complementary metal-oxide semiconductor (CMOS) sensor detects the location of the finger and therefore the key it is hitting.


Laser keyboards can be used anywhere with a flat surface

DID YOU KNOW? The first mechanical keyboard was patented by Englishman Henry Mill in London in 1714

BEHIND THE KEYS

How mechanical and membrane keyboards turn touch into text



RUBBER DOMES
Silicone domes are used to press one layer of conductive membrane through holes in a central non-conductive layer and provide feedback to the user.

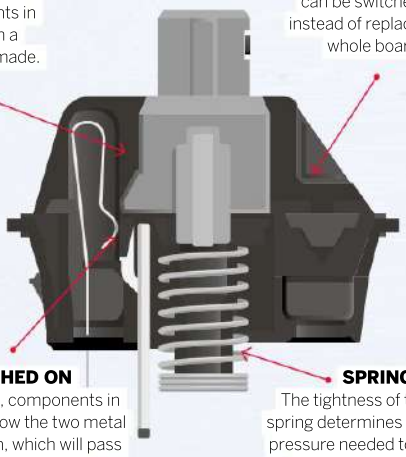
TOP MEMBRANE
When a keystroke is made, the top membrane and key contact pads connect with the current-carrying bottom membrane.

CENTRE MEMBRANE
This non-conductive layer separates the top and bottom membranes to prevent them from touching and accidentally creating a false keystroke.

BOTTOM MEMBRANE
When the key is at rest the bottom membrane is flowing with electrical current. However, the circuit remains open.

SWITCHED OFF
A thin piece of metal carrying an electrical current is blocked from connecting with metal components in the stem when a keystroke is not made.

MOUNTING
One of the benefits of mechanical keys is their individual mountings. Should one key break, this bottom housing can be switched out instead of replacing the whole board.



SWITCHED ON
When pressed, components in the stem will allow the two metal pieces to touch, which will pass a current and alert the circuit board of a keystroke.

SPRING
The tightness of the metal spring determines the vertical pressure needed to register a keystroke and provides feedback to the user.

QWERTY MYSTERY

The typewriter was invented with all the letters of the alphabet in order along each row of keys. However, Sholes and his partner James Densmore patented a new key order called QWERTY, named for the first six letters of the keys. It remains unclear as to why exactly Sholes reordered the alphabet, but a commonly accepted explanation is that it was due to the mechanics of the typewriter. With the way the letter plates were placed within the typewriter, typing common combinations of letters that were close alphabetically, such as 'he', caused the machine to jam. Therefore Sholes separated the letters into the QWERTY format to prevent any further failings.

A QWERTY keyboard keeps common combinations as far away as possible

© Getty / Illustration by Ed Crooks

HOW DOES GOOGLE EARTH WORK?

The app that puts the world in the hands of anyone with a smartphone or computer

WORDS **MARK DAVIS**

Google Earth is a unique geo-mapping and tagging program that uses composite imagery to form a comprehensive, interactive map of Earth. By stitching together more than a billion satellite and aerial images, the application provides a versatile tool that allows individuals and groups to track climate change, discover unknown geographic and ecological features and record history. This digital cartography tool continues to be a useful resource for governments, private organisations and individuals who want to track and tag geographic data to a myriad of ends.

By collecting and curating enormous amounts of data, Google has made it possible for conservationists to observe the shifting patterns of flora and fauna on a global scale, for governments to observe the growth of cities worldwide and for individuals to tell their personal stories in a unique way.

When a user selects 'Street View', they are taken down to street level and shown images taken by a special road vehicle with a 360-degree camera

THE BIRTH OF GOOGLE EARTH

Launched in 2005, Google Earth was the first widely available interactive composite map of our world. Today Google Earth features 3D reconstructions, annotation tools and satellite imagery provided by NASA dating all the way back to 1984, allowing users to virtually travel back in time. As new images become available via satellite and aerial imagery, Google Earth's map is constantly updated to reflect the ever-changing world around us.

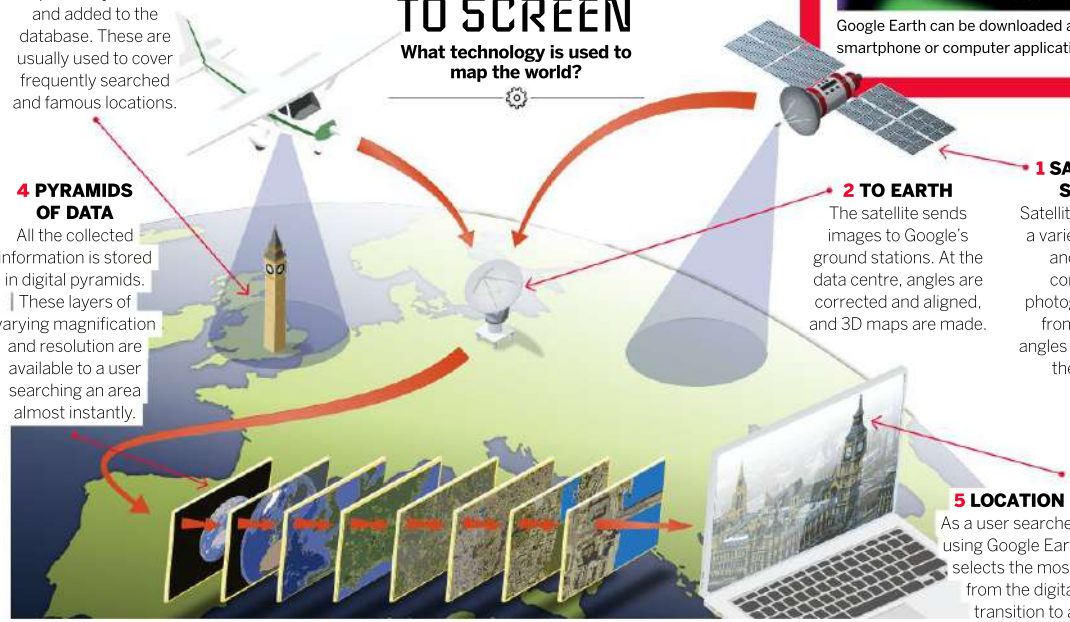
The imagery and data used by Google Earth is collected through partnerships with NASA, National Geographic and others, making it quite a collective effort. The development team consists of user experience designers and engineers, who are mostly focused on improving the app's ability to send data.

Google Earth can be downloaded as a smartphone or computer application

Did you know?
Google Earth's images are just one to three years old

FROM SATELLITE TO SCREEN

What technology is used to map the world?



1 SATELLITE SHOTS
Satellites owned by a variety of public and private companies photograph Earth from multiple angles as they orbit the planet.

2 TO EARTH
The satellite sends images to Google's ground stations. At the data centre, angles are corrected and aligned, and 3D maps are made.

3 AERIAL SHOTS
Closer imagery is captured by aircraft and added to the database. These are usually used to cover frequently searched and famous locations.

4 PYRAMIDS OF DATA
All the collected information is stored in digital pyramids. These layers of varying magnification and resolution are available to a user searching an area almost instantly.

5 LOCATION SELECTION
As a user searches and navigates using Google Earth, the software selects the most relevant data from the digital pyramid to transition to and display.

© Alamy / Getty / Illustration by The Art Agency: Nick Sellers

Future Genius

THE BRAND NEW

★ EDUTAINMENT ★ BOOKS FOR KIDS!

For ages 7+

OUT NOW!

WATCH VIDEOS WITH OUR INCREDIBLE INTERACTIVE EXPERIENCE

on SALE now

★ Solar System ★ Cool Chemistry
★ Human Body ★ Animal Kingdom
★ Ancient Egyptians ★ Computers & Learn to Code

GET YOURS NOW FROM MAGAZINESDIRECT.COM
AND ALL GOOD SUPERMARKETS AND NEWSAGENTS

✚ Puzzles ✚ Activities ✚ Experiments ✚ Facts ✚ More!

HYDROGEN BUS POWER

Inside the world's first clean-energy double-decker bus: the Hydroliner

WORDS AILSA HARVEY

Due to global demand, we are running out of the fossil fuels that are used to power vehicles on the roads. Hydrogen, on the other hand, is accessible everywhere across the globe and has a high energy content per unit of weight. There is plenty of hydrogen on Earth to be used as vehicle fuel, being the third most abundant element on its surface after oxygen and silicon – but it doesn't exist naturally in its pure form. In order to produce the fuel, hydrogen needs to be extracted from compounds such as water and methane.

The first hydrogen-powered car was invented in 1806, but after two centuries this technology now exists in much larger machines. Hydrogen as a fuel presents a more sustainable, zero-emission alternative to fossil fuels. Its potential is being shown in public transport, too, in the form of the first hydrogen double-decker bus: the Hydroliner.

Manufactured by Wrightbus, the Hydroliner releases pure water from its exhaust. The electrical energy created inside this type of vehicle is produced in a fuel cell that replaces diesel engines. The fuel cell mixes pure hydrogen with an influx of oxygen. The end product is electricity, with heat and water as by-products. In cities where the surrounding air is heavily polluted, hydrogen vehicles can be used to reduce greenhouse gas emissions for clearer air and to help slow global warming.

Did you know?
The first double-deckers emerged in 1847

WHERE ARE THE FUEL STATIONS?

With a big appetite for hydrogen fuel, the Hydroliner bus needs to be driven within range of a hydrogen fuel station. These services currently vary based on demand in the area. The fuel can be produced at the station, with the gas made locally and then transported to the site.

When topping up the hydrogen tanks, the process for the driver is similar to filling up a petrol or diesel tank, though the high pressure that hydrogen leaves the pump at often makes loud noises. When the pump makes contact with the bus, it clicks into place to ensure contact before releasing any fuel.

The Hydroliner buses that have been distributed in Aberdeen, Scotland, are powered by hydrogen that is produced locally. Electrical energy is created on wind and water farms and used to remove the hydrogen from water.

At the end of 2020, there were 553 hydrogen fuelling stations in the world

© Wrightbus

HYDROLINER COMPONENTS

How is Wrightbus' hydrogen-powered vehicle engineered?

Hydrogen storage can be accessed from the back of the Hydroliner

The world's first double-decker hydrogen fuel cell-powered electric vehicle

GAS STORAGE
1,120 litres of hydrogen is stored in impact-resistant cylinders at high pressure.

FUEL CELL
The hydrogen is carried at a lower pressure to the fuel cell, where it is split into protons and electrons to form an electric current.

ELECTRIC PORTAL AXLE
Centrally placed, this device delivers electricity to the bus' wheels to turn them.

BATTERIES
Electricity made in the fuel cells is transported to the 48 KWh lithium battery pack to power the vehicle.

COOLING SYSTEM
By cooling the hydrogen, it becomes more dense. This means that more energy can be created from it per unit of volume.

REFUELLING POINT
Hydrogen is pumped into the bus at this point, a process that takes eight minutes to refill completely for a range over 250 miles.

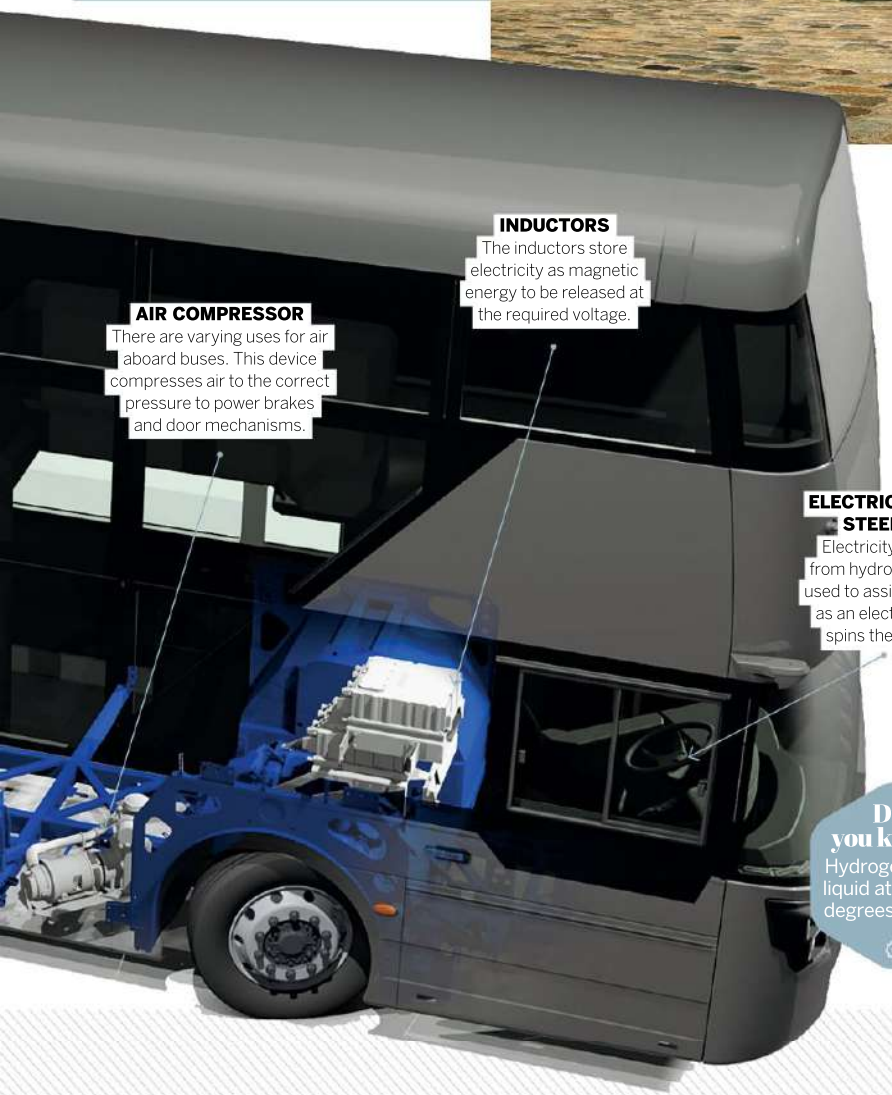
"The fuel cell mixes pure hydrogen with an influx of oxygen"

DID YOU KNOW? Seven months after launch, the Hydroliner had prevented 500,000 kilograms of carbon dioxide entering the atmosphere

PASSENGER EXPERIENCE

The Hydroliner can hold up to 86 passengers. These buses currently run in the cities of Birmingham, London, Belfast, Dublin and Aberdeen in the UK and Ireland, working to reduce pollution for residents and visitors. Because the chunkiest items, the hydrogen cylinders, slot into the back of the bus, and without a central engine taking up significant space, the passenger area is not compromised. And instead of a running engine creating background noise, there is minimal sound. It bodes well for quieter cities and is less disturbing to peaceful countryside routes.

There are 20 Hydroliner buses in use in Birmingham



INDUCTORS
The inductors store electricity as magnetic energy to be released at the required voltage.

AIR COMPRESSOR
There are varying uses for air aboard buses. This device compresses air to the correct pressure to power brakes and door mechanisms.

ELECTRIC POWER STEERING
Electricity created from hydrogen is also used to assist steering, as an electric motor spins the wheels.

Did you know?
Hydrogen turns liquid at -252.87 degrees Celsius

5 FACTS METHODS FOR PRODUCING HYDROGEN

1 GASIFICATION
Hydrogen, carbon monoxide and carbon dioxide are formed when natural gas reacts with high-pressure steam.

2 ELECTROLYSIS
Water can be manipulated and split into hydrogen and oxygen when an electric current passes through it.

3 RENEWABLE LIQUID REFORMING
At high temperatures, steam can be used to remove hydrogen from liquid fuels such as ethanol.

4 FERMENTATION
Bacteria can be used to break down organic matter, releasing hydrogen as it does .

5 WATER SPLITTING
Photoelectrochemical water splitting involves turning solar energy into electricity to remove hydrogen from water.

© Wrightbus / Getty

How our CLIMATE is CHANGING

Here are eight signs of the human impact on Earth's climate and environment

WORDS SCOTT DUTFIELD

Climate change is described as a large-scale and long-term shift in Earth's climatic patterns and average temperatures. These shifts have been exacerbated by human activity. For example, greenhouse gas emissions of carbon dioxide (CO_2) reached record highs of 417 parts per million in May 2020. CO_2 naturally soaks up infrared radiation from the Sun and distributes the heat it produces across Earth, acting like a big blanket. This results in the rise of global temperatures, causing widespread alterations in Earth's climate. Since 1880, Earth's combined land and ocean temperature has increased by an average rate of 0.08 degrees Celsius each decade.

As a result, countless aspects of our environment and ecosystems are altering. From record-breaking forest fires to unprecedented shifts in weather, there are many warning signs from all corners of our planet that show our world is changing.

Humans release pollutants into the air from industry

DID YOU KNOW? Since 1970, the global surface temperature has risen faster than in any other 50-year period over the past 2,000 years

ANIMAL MIGRATION

1 Seasonal cues play a role in informing animals when it's time to migrate, when to find a partner to mate with and when and where they can find food. The migration and reproduction timelines of several Arctic animals have changed over the years in response to the effects of climate change. Researchers have discovered that eagles in the Arctic have been migrating half a day earlier each year between 1991 and 2019, which has led to a current migration timing that starts two weeks earlier. Similarly, Arctic caribou populations have adapted to the changing seasons and are having their offspring earlier to coincide with their changing environment.

Caribou crossing the Arctic National Wildlife Refuge in Alaska

Large algal blooms on Lake Balaton, Hungary, taken 31 August 2019

ALGAL BLOOMS

2 As waters warm around the world and global emissions of CO_2 increase, harmful algae can thrive. Large algal blooms tend to appear on lakes and shorelines during the summer, but these blooms are getting bigger. Researchers at the Carnegie Institution for Science conducted a global study in 2019 and found that summertime algal blooms increased in more than two-thirds of the 71 sampled lakes, which spanned 33 countries across six continents, over the last 30 years. These blooms can be deadly: they can form dead zones that starve marine life of oxygen and light, and some can even release lethal toxins. In 2020, a 14-mile toxic algal bloom called the 'red tide' drifted along the Florida coastline, killing more than 100 manatees and 127 dolphins.

CORAL BLEACHING

3 Between a quarter and a third of all marine species rely on coral reefs to survive at some point in their lives, but extreme bleaching events are destroying them. As global temperatures increase, bleach events are becoming more frequent. A rise in temperature, along with increased levels of carbon dioxide, strip away the mutualistic algae that are vital to the coral's survival, leaving the coral bleached white and dead. In 2016 and 2017, 50 per cent of corals in the Great Barrier Reef were killed. Coral reefs in all 29 reef-containing World Heritage Sites could be lost by the end of the century if current global CO_2 emissions aren't reduced.

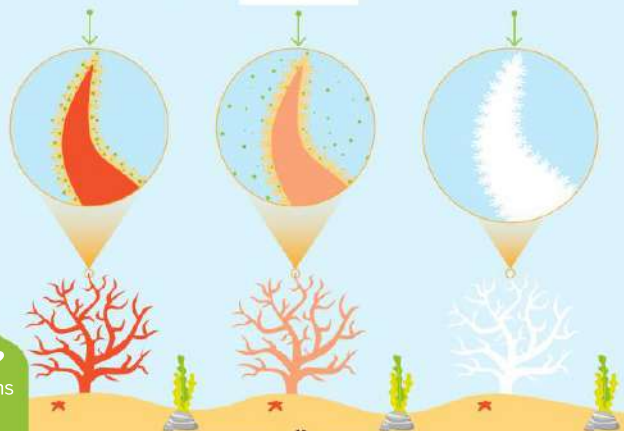
Bleached corals on the Great Barrier Reef, Australia, after a mass bleaching event in 2019

Did you know? In 2019 humans emitted 36 gigatonnes of CO_2

HEALTHY CORAL
Zooxanthellae algae live within the tissue of corals for protection, and in return the algae provide corals with oxygen and nutrients.

STRESSED CORAL
When temperatures increase, pollution levels rise and waters become more acidic. Algae begin to evacuate, reducing the amount of nutrients corals receive.

BLEACHED CORAL
Once all the algae has vacated, corals lose their food source. Algae also give corals their vibrant colours – without them, they turn ghostly white.



HOW CORAL BECOMES BLEACHED

A breakdown in a symbiotic relationship leads to the demise of coral

© Getty / Lauren Dauphin, using Landsat data from the U.S. Geological Survey

Heavy rain flooding the Nine Elms district of London, 25 July 2021

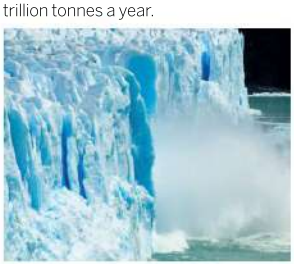
A coastal cliff fall on Dorset's Jurassic Coast, England

FLOODING

4 Extreme flooding occurs in built-up areas where urbanisation has changed the landscape of floodplains or low-lying coastal regions. A rise in global temperatures increases the likelihood of extreme weather, which leads to flooding. As the atmosphere warms, it holds more moisture, meaning heavier precipitation. For around every 0.6-degree-Celsius increase the atmosphere can hold around four per cent more water vapour. Studies show that the number of extreme precipitation events in the US could increase to two to three times its historical average by the end of the century.

MELTING THE ICE

5 Around ten per cent of Earth's land is covered in ice, and almost 90 per cent of that is in Antarctica. Greenhouse gas emissions and a rising global temperature have caused these vital ice stores to melt. Before the year 2100, it's estimated between a third and half of the world's remaining glaciers will have melted. Since the 1990s, Greenland and Antarctica have lost around 6.6 trillion tonnes of ice. The rate of ice loss is also increasing; researchers found that between 1994 and 2017, the rate of ice loss accelerated by 57 per cent, from around 800 billion tonnes to around 1.2 trillion tonnes a year.


Melting ice has a knock-on effect of increasing sea levels

COASTAL EROSION

6 Coastal erosion occurs when the water of the ocean beats against coastal rocks and reduces them to rubble, eventually grinding them into sand. As sea levels rise around the world – a knock-on effect of melting ice caps – the water can extend further up coastal regions, increasing the rate of erosion. Erosion at the coastline can occur in several ways: simple abrasion from waves can grind rock and stone away, but it can also dredge up rock and stone from the seabed and throw them against the cliffs, chipping away at the coastline. Hydraulic action also occurs when air trapped between the rocks of a cliff compresses under the force of the wave, weakening structural integrity. Britain has some of the fastest-eroding coastlines in Europe and loses around four metres of coastline each year in heavily affected areas.

LANDLOCKED LAKE DRY-OUT

7 Endorheic lakes are landlocked and don't drain into other bodies of water. Water levels are determined by precipitation and the rate of evaporation; this makes them a useful tool as indicators of climate change and rising global temperatures. Between 2002 and 2016, approximately 106.3 gigatonnes of water was lost from the endorheic system worldwide. Water loss from these lakes can put pressure on local communities that rely on them, as well as displacing water into other water systems, which could cause flooding.

The lakebed of Suesca Lagoon, Colombia, is dried out and thirsty for rain

ANTARCTICA'S ICE MELT

How the South Pole has changed over the last 30 years

Antarctica is a large continent of ice that experiences fluctuations in the amount of sea ice that surrounds it. During the winter months this ice expands, retreating again during the summer as the weather gets warmer. Since the beginning of satellite observations of the icy continent in 1979, Antarctic sea ice has increased by one per cent per decade. However, since 2014 Antarctica has experienced several drops in sea ice production. In 2017 Antarctica had a record-breaking low annual sea ice coverage of 815,000 square miles – 71,000 square miles below the previous minimum, which occurred in 1997. The images on the opposite page show how this ice coverage has changed over the decades, during the Antarctic summer retreat.

DID YOU KNOW? 2020 was the second-hottest year on record, with 2016 remaining the hottest

WILDFIRES

Rising global temperatures cause increased evaporation and the drying out of the world's forests, along with the soil they stand on, making them more flammable. Around 90 per cent of wildfires are ignited by humans; the rest are caused by natural means, such as lightning and even volcanic activity. Fire only needs three things to blaze: fuel, oxygen and heat. When wood is heated to the point it burns – known as its flash point – it releases hydrocarbon gas that combines with the oxygen in the air and combusts to produce fire. As climate change continues to turn forests into kindling, these fires have increased in size – California lost a record-breaking 4,257,863 acres of forest in 2020.

Fire is absolutely devastating to an ecosystem and wildlife

HOW WILDFIRES SPREAD

Once one gets going, it takes a lot of work to stop it

1 IGNITION
Trees ignite when they reach their flash point, which is a temperature of around 300 degrees Celsius.

4 CROSSING BARRIERS
Embers are able to cross over natural barriers, such as rivers and roads, on the wind. This allows the fire to spread even greater distances.

5 TOWN FIRES
Buildings can perpetuate the spread of a wildfire if they are positioned close together. This allows flames to hop from one building to another.

2 TRAVEL
Several factors contribute to the way a wildfire spreads, such as winds carrying hot embers, the topography of forests and the weather.

3 FIRE DAMAGE
Radiant heat, embers and smoke are the main causes of damage to urban areas affected by wildfires.

6 SMOKE
The smoke emitted from a wildfire is largely made up of water vapour. However, it also contains several harmful compounds such as carbon dioxide and monoxide, nitrogen oxide and fine toxic particles.

AR zone
SCAN HERE

Did you know?
Arctic sea ice is reducing by 13 per cent per decade

© Getty / illustration by Nicholas Forder

CLIMATE CHANGE by numbers

2.3 TO 5.4 METRES

Sea-level rise by 2300 under a high-emission scenario

0.6 TO 1.1 METRES

Sea level rise by 2300 under a low-emission scenario

2,400 billion tonnes of CO_2 have been emitted globally since the late 1800s by human activity

HUMANS HAVE BEEN RESPONSIBLE FOR 90 PER CENT OF THE RETREAT OF GLACIERS SINCE THE 1990S

8 TO 10%

The percentage of total greenhouse emissions between 2010 and 2016 caused by food waste

EVERY YEAR, HUMAN ACTIVITIES EMIT 40 BILLION TONNES OF CO_2

3X

Sea level rises have almost tripled compared to those between 1901 and 1971

FIVE YEARS

2015 to 2020 have been the hottest years on record since 1850

1.5°C

Predicted rise in global temperature by 2040

1.1°C

The global temperature increase since preindustrial times

TO HAVE A CHANCE OF KEEPING GLOBAL WARMING BELOW 1.5°C, HUMANITY CAN ONLY EMIT ANOTHER 400 BILLION TONNES OF CO_2

© Getty

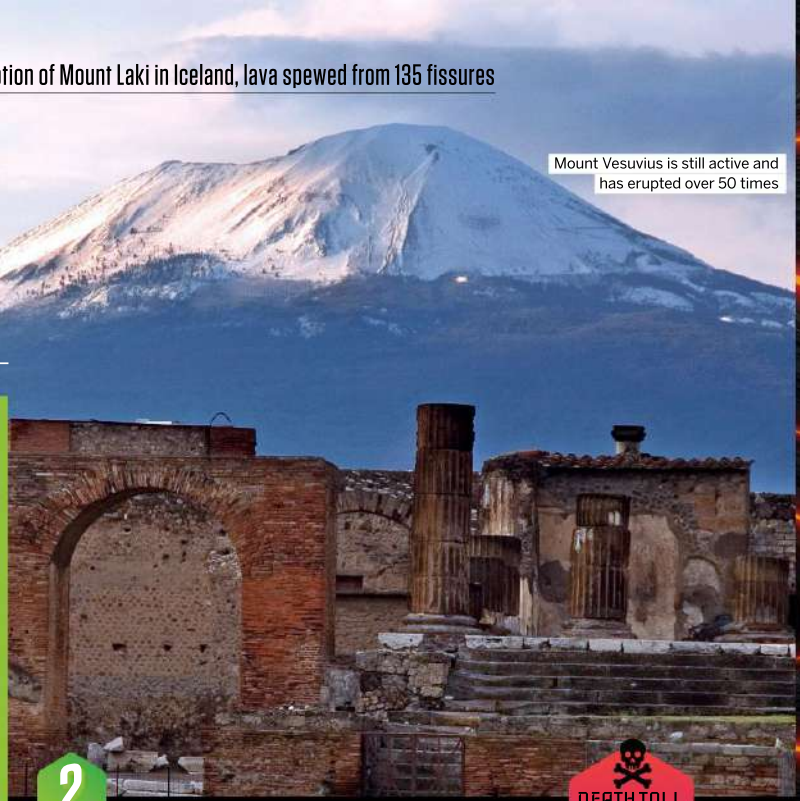
10 DEADLY VOLCANIC ERUPTIONS

How Earth's fiery outbursts remind us of our planet's power and unpredictability

WORDS **AILSA HARVEY**

As a species that has evolved to suit conditions on the surface of Earth, humans don't fare well when the planet spills out its innards. Searing magma from the flowing mantle below the crust can push through ruptures in the outer layer. Local scientists can sometimes predict these explosions by monitoring volcanoes' behaviour or documenting those that are particularly volatile. Active volcanoes are often classed as 'dangerous' and extinct volcanoes as 'safe', but what happens when one dismissed as dormant has a change of heart? Throughout history, the volcanoes that have claimed the most lives held an element of mystery and surprise, with incredible and terrifying power lurking within. These are the world's deadliest eruptions.

DID YOU KNOW? During the 1783 to 1784 eruption of Mount Laki in Iceland, lava spewed from 135 fissures



Mount Vesuvius is still active and has erupted over 50 times

DEATH TOLL 10,000+

1 MOUNT KELUD'S LETHAL LEGACY

EAST JAVA, INDONESIA

One of Mount Kelud's most significant outbursts occurred over five centuries ago, in 1586. Though hosting a full crater lake, the volcano was ready to blow, with lethal power. The hot mudflows triggered by the eruption crushed and buried anything in their path, killing over 10,000. Following the eruption – the largest ever recorded from the volcano – no activity was recorded for the next 75 years.

Another deadly eruption occurred on 19 May 1919, releasing a relentless mudflow with temperatures around 1,000 degrees Celsius over East Java, killing over 5,000 people. Also known as a lahar, it moved at 37 miles per hour and was triggered by the eruption, which displaced the crater lake containing 40 million cubic metres of water at the summit. As the scalding water flowed down the volcano it combined with rock and mud to form a deadly cascade that swept through 100 villages.

The devastation of 1919 led to engineering work to build a tunnel into the volcano. This lowered the lake's water level, with the water draining into the tunnel on the crater's southwestern side. In later eruptions, this prevented such large volumes spilling out from the top.

This volcanic rock was transported over 25 miles during the 1919 eruption

DEATH TOLL 16,000

2 VESUVIUS AND THE LOST CITIES

CAMPANIA, ITALY

Mount Vesuvius spent centuries being peacefully still before exploding with vigour in 79 CE. Towering 1,280 metres above the southern Italian cities of Pompeii and Herculaneum, around midday on 24 August, Vesuvius showered these communities in hot rock and ash. Studies of the bones of Herculaneum residents suggest that the liquid in many of the victims' bodies was boiled instantly upon contact with the volcano's contents. For those in Pompeii who hadn't fled by the next morning, a second release of gas and ash from the volcano swept into the city to claim their final breaths. Following this, a large flooding of volcanic mud and debris buried both Roman cities, only for them to be rediscovered during excavations throughout the 1900s.

Lightning can form from the electrical discharge of an eruption

© Getty / Wiki Commons: Tropen Museum

DEATH TOLL
23,000

3 MALARIA OUTBREAK OF SANTA MARÍA

After at least 500 years of inactivity, Santa María volcano in Guatemala exploded in October 1902, claiming the lives of more than 6,000 people. Additionally, the release of ash was fatal to local birds, allowing their mosquito prey to thrive. This led to many more people dying indirectly from malaria outbreaks.

4 ICELAND'S FAMINE

Starting on 8 June 1783, 3.7 quadrillion gallons of lava erupted from Mount Laki, Iceland, travelling over 600 square miles. Around 9,000 people died, and those who survived faced the resulting famine. Surrounding farms were burned or poisoned, killing cattle and crops along with 25 per cent of Iceland's population.

5 TSUNAMI SURGE

The force released from Mount Unzen in 1792 was the beginning of a domino effect and Japan's most devastating volcanic event. As the eastern side of the volcano collapsed, a landslide travelled across Shimabara city and into the surrounding sea, triggering a tsunami. Together the eruption and tsunami caused around 15,000 deaths.

6 TOBA'S ACID RAIN

Around 75,000 years ago, Toba volcano in Indonesia caused sulphuric acid rain to fall at both poles after injecting masses of sulphur dioxide into the atmosphere. Some studies suggest the change in climate allowed only 10,000 humans to survive.

7 PINATUBO'S WEIGHT

When a typhoon followed the eruption of Mount Pinatubo in 1991, the roofs of surviving buildings fell and crushed their inhabitants. This is because the rain saturated the fallen ash, increasing its weight and causing roofs to cave in.

8 NEVADO DEL RUIZ: A GLACIAL BURN

CENTRAL ANDES, COLUMBIA

You wouldn't expect an icy mountain to burn you alive, but Colombia's Nevado del Ruiz volcano did just that. On 13 November 1985, an explosion from its large Arenas crater transformed the summit's snow and glaciers into the start of a fatal mudflow. After monitoring the early activity – from its first stir until the evening – scientists said the event posed no danger to nearby residents. This meant that many who lived beneath the mountain in the city of Armero were asleep when the mud began to race down the slopes towards them. This was the first major eruption of the 5,321-metre volcano in around 150 years.

Nevado del Ruiz is situated in central Columbia

Mount Laki can be found in Vatnajökull National Park, Iceland

DID YOU KNOW? On 27 August 1883, Krakatoa's explosions were heard 1,930 miles away in Perth, Australia

DEATH TOLL
36,000+

BEFORE 1883
Krakatoa originally had three peaks. It had not experienced an eruption for at least two centuries.

WARNING SIGNS
From May until August, ships that sailed past the volcano – which lies between Java and Sumatra – reported seeing ash and dust.

9

CHAOS ON KRAKATOA

How a natural disaster in 1883 shaped the landscape on the Indonesian island of Krakatoa

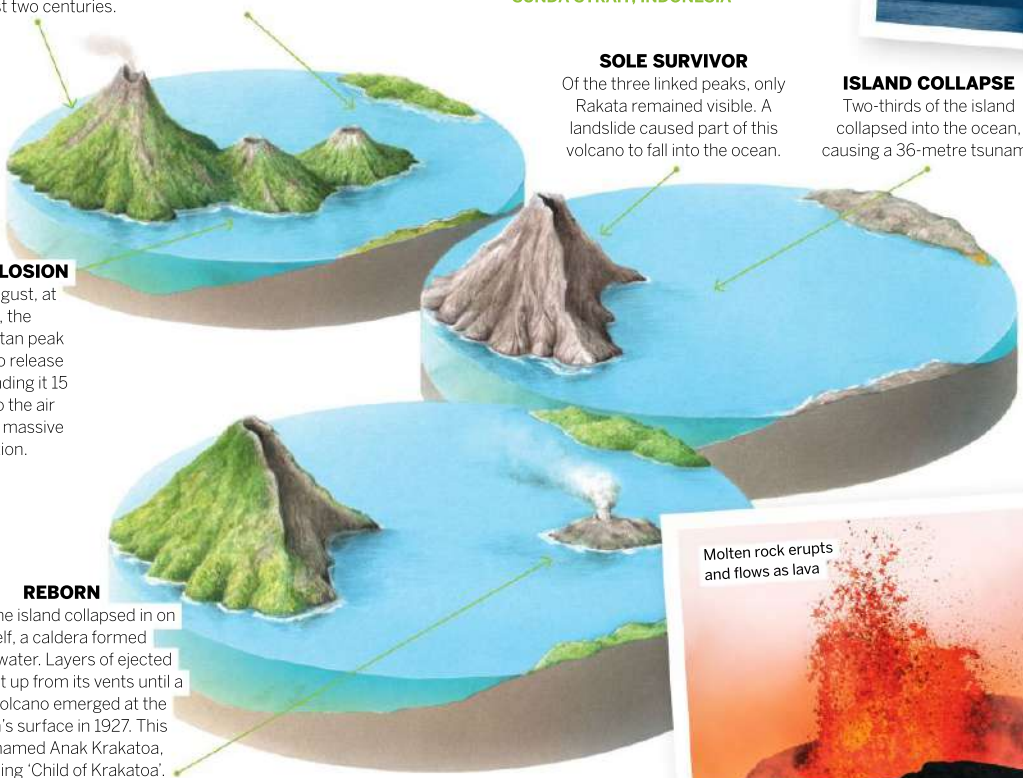
SUNDA STRAIT, INDONESIA

After Krakatoa's 1883 eruption, skies darkened for 275 miles and debris was flung even further

SOLE SURVIVOR
Of the three linked peaks, only Rakata remained visible. A landslide caused part of this volcano to fall into the ocean.

ISLAND COLLAPSE
Two-thirds of the island collapsed into the ocean, causing a 36-metre tsunami.

THE EXPLOSION
On 26 August, at 13:00, the Perboewatan peak was first to release debris, sending it 15 miles into the air above in a massive eruption.



REBORN
After the island collapsed in on itself, a caldera formed underwater. Layers of ejected lava built up from its vents until a new volcano emerged at the ocean's surface in 1927. This was named Anak Krakatoa, meaning 'Child of Krakatoa'.

Molten rock erupts and flows as lava

10

MOUNT TAMBORA: THE DEADLIEST OF THEM ALL

SUMBAWA ISLAND, INDONESIA

Of all recorded volcanic eruptions, Mount Tambora of Indonesia takes the title of deadliest. 10,000 people on the island of Sumbawa died instantly in the 1815 blast, but the greater environmental impact caused more than 71,000 deaths. Tambora's gigantic eruption was so powerful that soldiers hundreds of miles away mistook its sound for cannon fire, and lava flowed continuously from the volcanic site for two hours.

As the hot lava met the ocean it reacted with the cold water to send ash high into the air, spreading it even further. For hundreds of miles dark, ash-filled skies and falling remnants prevented crops from growing and spread disease, while acid particles, spread by Tambora's sulphurous waste, lowered temperatures across the Northern Hemisphere. Crops froze, contributing to starvation, and many died due to the colder, harsher climates the eruption caused.

Mount Tambora has a caldera nearly four miles wide

© Alamy / Getty / Wikimedia Commons: NASA / Wikimedia Commons: Jeffrey Marso / Illustration by The Art Agency / Peter Scott

Komodo National Park, Coral Triangle

AMAZON OF THE OCEAN

Explore the lively reefs of Southeast Asia's Coral Triangle

WORDS **JENNIFER LEMAN**

The Coral Triangle is a vast network of coral reefs that dot the waters surrounding the Philippines, Indonesia, Malaysia, Papua New Guinea, the Solomon Islands and Timor-Leste. Also known as 'the Amazon of the ocean', this expansive underwater ecosystem in Southeast Asia is a hotspot for marine biodiversity, hosting 30 per cent of the world's coral reefs and spanning 2.3 million square miles. From humpback whales to humphead wrasses, a wide variety of sea creatures survive and thrive along the reefs of the Coral Triangle.

The region is home to more than 500 species of reef-building corals, which have adapted to an array of habitats. Some corals are adapted to live at greater depths and in cooler waters. Other corals in the region have evolved to thrive in muddy, sediment-rich waters as opposed to the crystal-clear conditions most corals prefer.

Some of the animals that call the Coral Triangle home include nearly a third of the world's coral-reef fish species, six of the world's seven species of sea turtle, dugongs, damselfish and manta rays.

The islands in Raja Ampat, Indonesia, are at the centre of the Coral Triangle

WHY ARE THESE REEFS SO SUCCESSFUL?

There are many theories as to why reefs in this part of the world host such an abundance of life. The wide range of habitats in the region – from volcanic islands with rocky shores to white sand beaches to mangrove forests – created a wide range of species. Scientists suspect that the diversity of landscapes has forced species to adapt to the geographically complex reef system.

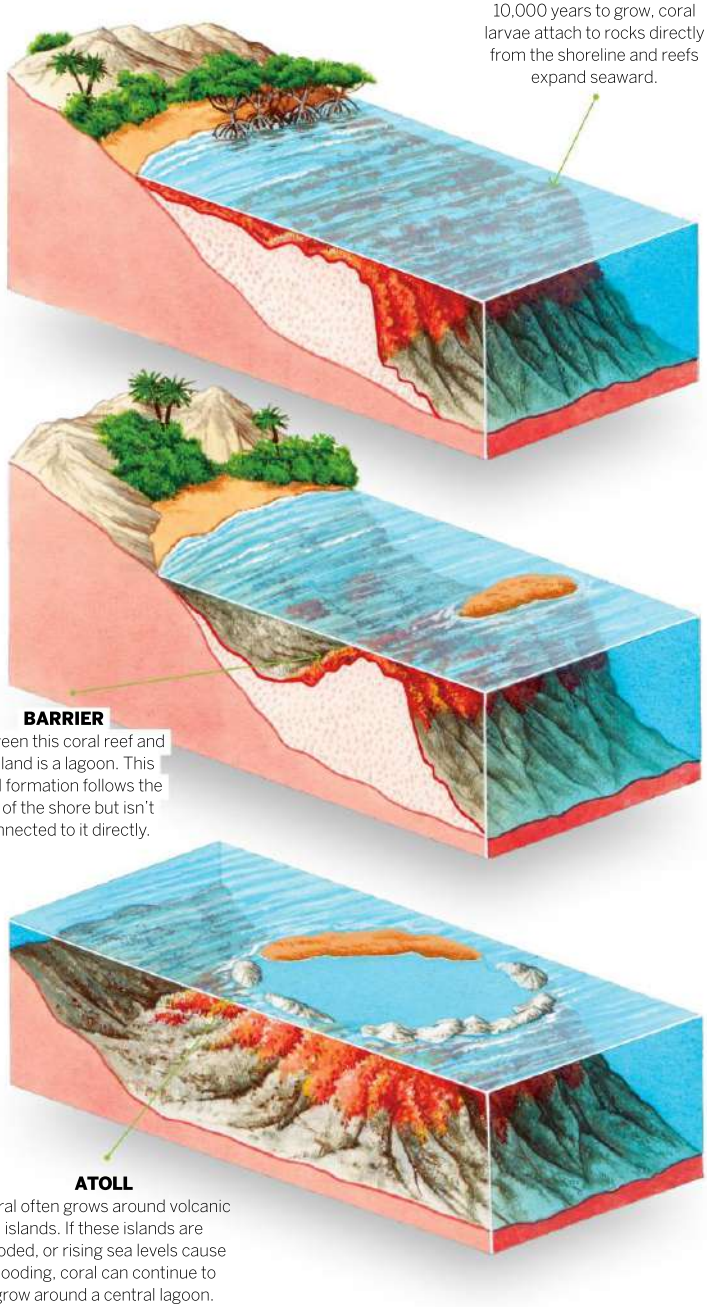
It's thought that many species originated in isolated archipelagos in the Indian and Pacific oceans, such as Hawaii or the Maldives, and were then swept to the Coral Triangle by prevailing currents. These mixed with species already living in the region to form new ones. As geographic area increases, the risk of extinction decreases. If a species inhabits a large area, scientists think there's less chance the organism will go extinct if something happens to one part of the reef where that species lives.

The biodiversity of the Coral Triangle is being protected by Indonesia, Malaysia, the Philippines, Papua New Guinea, the Solomon Islands and Timor-Leste as part of the Coral Triangle Initiative

DID YOU KNOW? 75 per cent of the world's coral species can be found within the Coral Triangle

TYPES OF CORAL REEF

How different coral formations shape the seabed



FRINGING
This is the most common coral formation. Taking up to 10,000 years to grow, coral larvae attach to rocks directly from the shoreline and reefs expand seaward.

BARRIER
Between this coral reef and the land is a lagoon. This coral formation follows the line of the shore but isn't connected to it directly.

ATOLL
Coral often grows around volcanic islands. If these islands are eroded, or rising sea levels cause flooding, coral can continue to grow around a central lagoon.

5 OF THE TRIANGLE'S MANY SPECIES

1 LOGGERHEAD TURTLE
This is one of the Triangle's six different turtle species. Loggerheads eat hard-shelled organisms such as crabs. As they break up crab shells the turtles help increase the recycling of nutrients on the ocean floor.

2 DUGONG
These marine mammals, also known as sea cows, are the only predominantly plant-eating mammals in the Coral Triangle. They are found mainly in Indonesian waters.

3 TUNA
The Triangle's waters are abundant in tuna species, including bluefin, bigeye, yellowfin, skipjack and albacore tunas. 30 per cent of global tuna fish landings come from the Coral Triangle.

4 FIN WHALE
This is the second-largest animal in the world. The species, along with other whales, uses the Coral Triangle as a calving and feeding ground.

5 HUMPHEAD WRASSE
These fish can grow up to 1.8 metres in length and are one of the few animals that eat the crown-of-thorns starfish. This is vital for the Coral Triangle's survival, as just one of these starfish can eat six square metres of coral in a year.

© Alamy / Wikimedia Commons: Obsidian Soul / Getty

WHAT IS THE ARK OF THE COVENANT?

Does this fabled chest – said to hold tablets engraved with the Ten Commandments – actually exist?

WORDS **OWEN JARUS**

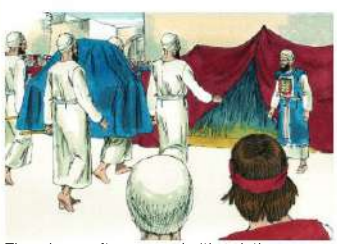
CHERUBIM
The Book of Exodus states that the two sets of wings on the ark's lid were built pointing upwards and facing each other.

CARRYING POLES
Two acacia-wood poles covered in gold were used to carry the ark.

According to the Hebrew Bible, the ark was constructed by the Israelites while they were camping out in the Sinai Desert after they fled Egypt. The Hebrew Bible doesn't specify when they fled Egypt, and there's debate among scholars as to whether there ever was an exodus from Egypt at all. The ark vanished when the Babylonians conquered Jerusalem in 597 BCE.

The Hebrew Bible states that this artefact has a number of seemingly magical powers. In one story the Jordan River stopped flowing and remained still while a group of priests carrying the ark crossed it. Other stories describe how the Israelites took the ark with them into battle, where the powers of the ark helped the Israelites defeat their enemies. When the ark was captured by the Philistines, outbreaks of tumours and disease afflicted them, forcing the Philistines to return the ark to the Israelites. Some stories describe how death would come to anyone who touched the ark or looked inside it.

There are two biblical stories describing the construction of the ark. The first – and most famous – is found in the Book of Exodus and describes how a large amount of gold was used to build the ark. The second version, found in the Book of Deuteronomy, briefly describes the construction of an ark made just of wood. Understanding the stories surrounding the ark is challenging because of the different accounts. The ark disappeared around 586 BCE, but in the last 3,000 years, Christians in Ethiopia have claimed that it lies hidden and guarded in a small chapel in the town of Aksum.



The ark was often covered with a cloth

WORSHIPPING THE ARK

The story of the construction of the ark as told in the Book of Exodus describes in great detail how God ordered Moses to tell the Israelites to build an ark out of wood and gold, with very precise instructions.

The Hebrew Bible directed that the Ark of the Covenant be placed within a movable shrine known as the Tabernacle. A curtain that prevented people from viewing the Ark of the Covenant was set up within the Tabernacle, and an altar and incense burners were placed in front of the curtain. The incense was made of gum resin, onycha, galbanum and frankincense, and was to be burned at morning and sunset.

During the reign of King Solomon, the First Temple, which is considered the holiest place in Judaism, was constructed in Jerusalem, and the Ark of the Covenant was placed in an inner sanctuary covered in gold.

THE INNER TREASURES

What items are hidden within the ark?

JAR OF MANNA
In the Hebrew Bible, this golden pot contained a flaky, bread-like substance called manna, which provided sustenance to desert travellers.

AARON'S STAFF
The staff of Moses' brother is said to be in the ark. In ancient Israelite culture a staff symbolised authority.

THE TEN COMMANDMENTS
Engraved into two stone tablets are the first ten commandments. These are important laws to live by in Judaism.

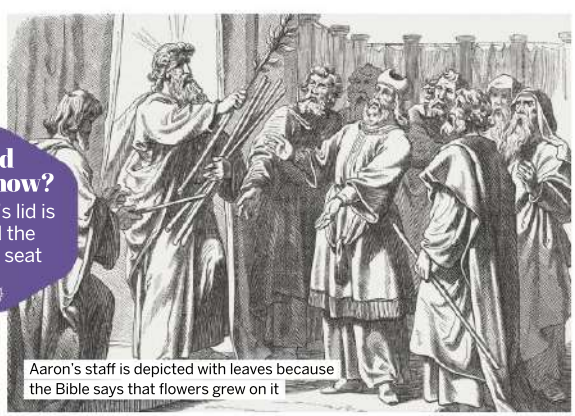
WERE THERE MULTIPLE ARKS?

It's possible that there were multiple arks that could have been used at the same or different times. "Before all the cultic affairs of the Israelites were concentrated exclusively in the capital, Jerusalem, there had been arks, probably of different sorts, wherever [God] was worshipped," wrote Tudor Parfitt, a professor of religion at Florida International University, who has done extensive research on the Ark of the Covenant. These early arks would have been "simple wooden containers". After Israeli worship became centralised in Jerusalem, the story may have been retold to describe one elaborate Ark of the Covenant made of gold.

The Book of Deuteronomy tells the story of the construction of a much more modest wooden ark

Four priests crossing the Jordan River with the ark, as mentioned in a Bible story about its magical powers

Did you know?
The ark's lid is called the mercy seat



Aaron's staff is depicted with leaves because the Bible says that flowers grew on it

© Getty / Illustration by The Art Agency: Sandra Doyle

WELCOME TO THE CRADLE OF CIVILISATION

How the ancient society of Pakistan's Indus Valley shaped the modern world

WORDS **AILSA HARVEY**

The Indus Valley Civilisation grew in South Asia during the Bronze Age

ANCIENT LIFESTYLE

Explore ancient life on the banks of the Indus River

CIVILISATION'S DEMISE

Between 1900 and 1800 BCE, the Indus Valley's cities were deserted. The reason for this abandonment is unknown, but historians think factors such as flooding, disease and the overuse of land may have contributed to it.

CRAFTING

Among the Indus artefacts recovered are jewellery, pots and clay figures made from shell, stone, gold and silver. Artists in these communities used natural materials such as stone to create imaginative ornaments.

CITY PLANNING

The first known planned cities were in the Indus Valley. Cities such as Harappa were purpose-built to accommodate large populations rather than evolving from villages into larger towns then cities.

FARMING

To cater for large cities, farmers had to prepare masses of food. Wooden ploughs were pulled by cattle to reduce human labour. Farmers understood that for the best results, seeds should be planted after the river had flooded, producing richer soil.

Urban environments are commonplace in today's age. A majority of countries are home to multiple crowded cities, built to function with dense populations. But when the world's first large civilisation was developing in the Indus Valley around 5,000 years ago, its people created and organised complex cities for the first time. The biggest was home to around 80,000 people.

The Indus River is the longest in Pakistan, and it became a crucial resource at the centre of a growing civilisation. As the water replenished the surrounding crops, the abundance of food and water allowed the Indus Valley to develop and flourish. People became experts at surviving and thriving in this environment. For example, farmers learned how to use the annual flooding to their own advantage by channelling floodwater towards their crops to aid growth.

Did you know?

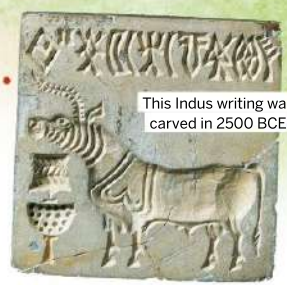
Lentils, wheat, and barely were grown in the valley

The beneficial geography of the Indus Valley made it a popular location to live, and over time populations boomed. The town planning that arose as a result paved the way for future cities, and today's urban areas share similarities with the Indus Valley. It consisted of many uniform straight roads that created neat city blocks. Wide streets allowed for two cattle-driven vehicles to pass each other, limiting congestion, and drainage systems were installed to maintain hygiene. While many questions are left unanswered about the intricacies of its culture, the logic and management behind one of the oldest known cities display many parallels to today's way of life.

DID YOU KNOW? The Indus language is unknown. Some experts think it was similar to Tamil, which is spoken in India and Sri Lanka

HUNTING
Children were taught to hunt from a young age. Knives, spears and arrowheads have been uncovered that were likely used as hunting tools.

HOUSING
People's houses were made of wood and stone. Wealthy families had larger homes that opened onto courtyards. Houses usually had flat roofs, which could be used for drying out crops. Drains and wells were engineered into homes to provide waste-flushing systems and water access.



This Indus writing was carved in 2500 BCE

EARLY WRITING

More than 400 symbols have been identified from the 3,000 pieces of Indus Valley writings that have been discovered. Indus script is the oldest known form of writing in the Indian subcontinent, preserved as carvings in hardened clay. The exact meaning of these symbols remains a mystery, however, as no one has yet been able to translate them.

The earliest examples of this writing were created between 3500 and 2700 BCE. Carved into the surfaces of pottery are singular symbols. Because they aren't drawn in sequence like thousands of other examples, historians believe this shows the early stages of the Indus script's development. Later examples include sequences of up to 26 shapes and symbols.

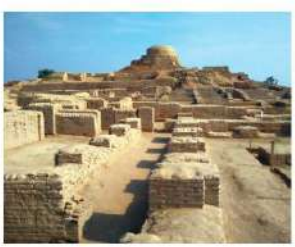
SETTLING
Settlements were built along the Indus River. This river stretches through Pakistan, northwest India and Afghanistan. Some 2,000 towns made up the Indus Valley Civilisation.

TRADING
Traders sailed long distances to exchange materials and goods from the Indus Valley. As Indus people were skilled at crafts, handmade stone tools were popular items to sell.

WHEN WAS THE CIVILISATION DISCOVERED?

The abandoned Indus Valley Civilisation was left to ruin for thousands of years. But in 1829 its brick remains were discovered by Charles Masson. Masson was a British soldier who reported seeing mounds of fire-baked bricks in the area. 30 years later, British colonial officials who were monitoring the building of a railway through the Indus Valley discovered more of these bricks.

These were the first pieces of evidence of the lost civilisation, which would lead to in-depth excavations. It wasn't until the 1920s that major excavation began. Archaeologists soon began to uncover the settlements of Harappa and Mohenjo-daro. Before becoming part of Pakistan, this area was the Punjab province of India. The cities beneath the ground were evidence that Indian civilisation began 1,500 years earlier than historians previously thought.



Mohenjo-daro was one of the largest cities of the Indus Civilisation

© Getty

FREE

300+ PAGES WORTH £20

2 eBooks FOR EVERY READER!

Grab yourself two fascinating, fact-packed **How It Works** specials for your digital device. Simply use the links below or scan the QR code to download

Book of Incredible Science, 2nd Edition

Journey from our early beginnings as a species to see how we came to be and how our immune system, emotions and fears developed. Meet some of science's greatest minds and discover how humans have created vaccines, illuminated the light spectrum and explained 'supernatural' phenomena. Explore the power behind nuclear fusion and the possibilities offered by quantum mechanics before stepping into a future where many diseases are a thing of the past and cloning yourself could be more than just the stuff of fiction.

World of Animals Annual, Volume 6

The animal kingdom is a fascinating, beautiful and complex world, but it faces an uncertain future. In this annual, we explore the threats faced by 25 of the world's most endangered creatures and meet the animals that owe their continued existence to the vital Endangered Species Act of 1973. There are also in-depth features on animal behaviour, weird and wonderful pets and the natural world's true survivors, while you can also get up close and personal with some of the planet's most remarkable creatures.

+ 2 DIGITAL POSTERS

5 SMARTPHONE WALLPAPERS

Claim yours now

SCAN THE QR CODES TO DOWNLOAD

eBooks
bit.ly/3z84Q2T

Posters and wallpapers
bit.ly/3z46Fxx

WORLDWIDE OFFER

Autumn Sale

3 ISSUES FOR £3/€3/$3

SPORT

TECH

MUSIC

HOBBIES

SUBSCRIBE TODAY

SAVE UP TO 93%

SEE THE ENTIRE RANGE ONLINE AT

www.magazinesdirect.com/autumn21

*TERMS AND CONDITIONS: Offer closes 30/09/2021. Offer open to new subscribers only. Savings are based on the newsstand cover price. After your first 3 issues, standard subscription pricing will apply. Please allow up to six weeks for delivery of your first subscription issue in the UK, and up to 8 weeks for overseas. Payment is non-refundable after the 14-day cancellation period unless exceptional circumstances apply. For full terms and conditions, visit www.magazinesdirect.com/terms. For enquiries please email help@magazinesdirect.com.

Could we build... TOTAL RECALL?

From Mars colonies to memory implants, a look at the science behind this 1990 classic

WORDS ANDREW MAY

DID YOU KNOW? *Total Recall* is based on a 1966 story by Philip K. Dick called *We Can Remember It for You Wholesale*

Remember the most interesting or exciting holiday you've ever had? Now that you're back in the routine of everyday life, there's still plenty of pleasure in simply conjuring up those memories. What if you could have all those memories without the expense of going on holiday in the first place? That's the premise of Paul Verhoeven's 1990 sci-fi blockbuster *Total Recall*. It's set in the year 2084, when humans have a well-established colony on Mars. Protagonist Douglas Quaid, played by Arnold Schwarzenegger, wants to go there, but he can't afford the ticket price. What he can afford, though, is the memory of a trip to Mars, implanted in his brain by a company called Rekall that specialises in 'virtual vacations' of this type.

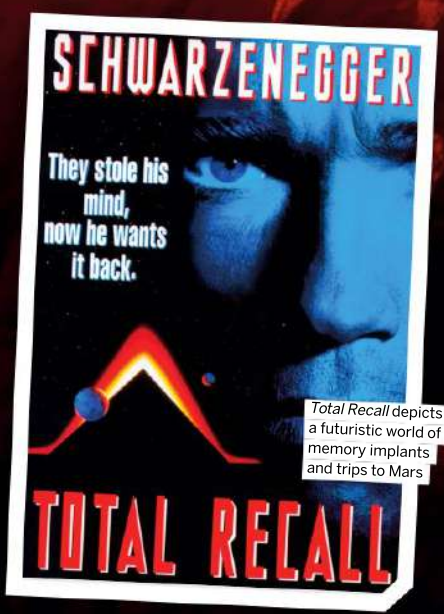
"Don't worry, things hardly ever foul up around here," a Rekall technician tells Quaid. But in his case things do foul up... in a big way. It turns out he's already been to Mars, but the memory of everything that happened there has been overwritten with bland fake ones. It's the cue for non-stop, edge-of-the-seat action in which Quaid travels to Mars, discovers a tyrannical conspiracy there and single-handedly defeats it.

Despite the over-the-top storyline, *Total Recall* has some remarkably good science in it, far superior to Hollywood's typical sci-fi fare. As we'll explore, the premise that starts it all off – the notion that memories can be altered or falsified – has a firm basis in reality, and many of the details that seemed so futuristic in 1990 now look like a practical proposition in the real world, from implanted tracking devices and walkthrough X-ray scanners to holographic projectors and chatty robot taxis. But it's the movie's portrayal of life on Mars that makes it so memorable – and this also has a solid basis in real science.

Did you know?
The Martian atmosphere is just 0.13 per cent oxygen

Mars is totally inhospitable to human life. The lack of a breathable atmosphere means the colonists are confined inside a large, pressurised dome, half-buried in the Martian terrain near the mines where they earn a living. Anyone venturing outside the dome has to wear a pressure suit and breathing apparatus, or else they'll die a nasty death. Oxygen, one of the few things that's totally free on Earth, is a valuable commodity on Mars. It's the whole basis for the near-dictatorship that exists there in *Total Recall*, with the villainous governor controlling the supply of oxygen and charging residents for the use of it.

There's another danger on Mars – both in the film and in reality – and that's the stream of lethal radiation emanating from the Sun. It's deflected away from Earth by our magnetic field, but Mars isn't so lucky. In the movie the excess radiation is responsible for an underclass of deformed mutants, but in the real world its effect would be even starker than that. It would simply kill anyone who was exposed to it for any length of time, unless they were properly shielded from it.



Total Recall depicts a futuristic world of memory implants and trips to Mars

Stages in the terraforming of Mars as an Earth-like atmosphere is established

TERRAFORMING MARS

Making a planet more Earth-like is called terraforming. In the case of Mars, we know that billions of years ago it really was quite Earth-like. Then it lost much of its atmosphere, leaving a barren, desert-like world. The lack of oxygen to breathe – a key plot driver in *Total Recall* – is just one of the consequences. Others include freezing temperatures and the need to wear pressure suits.

Terraforming also has to tackle the problem of solar radiation, which as well as being deadly was the main culprit in stripping away the Martian atmosphere. Here on Earth we're protected from this radiation by our planet's magnetic field. The artificial creation of such a field, together with thickening the atmosphere, is a key goal in terraforming Mars for settlement. As for oxygen, that can be produced naturally by plants and bacteria once a suitable ecosystem has been established there via a process called ecopoiesis.

© Alamy / NASA

MARS ECOPOIESIS TESTBED

This NASA proposal aims to study how an Earth-like ecosystem could be created on Mars

Mars landers are becoming increasingly sophisticated

INITIAL CONSTRUCTION
The whole base is built up around a robotic lander that delivers the first essential tools and life-support systems.

"Mars is totally inhospitable to human life"

CAREFULLY SELECTED SITE
The base is built on sloping terrain, so part of it is on the surface and part is underground.

TRANSPARENT DOME
This lets in sunlight for organisms that rely on photosynthesis to stay alive.

TRANSMITTER
This sends the data up to a satellite in Mars' orbit for onward transmission back to Earth.

RESEARCH AREA
Much of the initial activity would be scientific in nature, with this area containing laboratories and an observatory.

BIOSENSORS
These monitor the biological specimens to check that they are thriving and reproducing.

BOREHOLE DRILL
This penetrates a sample of Martian soil and then seals the whole unit to avoid planetary contamination.

MICROORGANISMS FROM EARTH
These might include cyanobacteria and other organisms that can survive in extreme conditions.

MODULAR WALL CELL
The module walls are more high-tech than they look, with aerogel insulation and a microbiological water ecosystem.

Mars colony milestones

2021
The first step was taken towards a human presence on Mars when an experiment on NASA's Perseverance rover made breathable oxygen.

2024
The SpaceX Starship, destined to be the main workhorse for Mars colonisation, will make its first crewed flight around the Moon.

2027
The first uncrewed Starships will land on Mars, carrying robots to prepare a base and refuelling station for later crewed missions.

2031
The first crew-carrying Starships will arrive on Mars, with a dozen or so engineers to start construction of Mars Base Alpha.

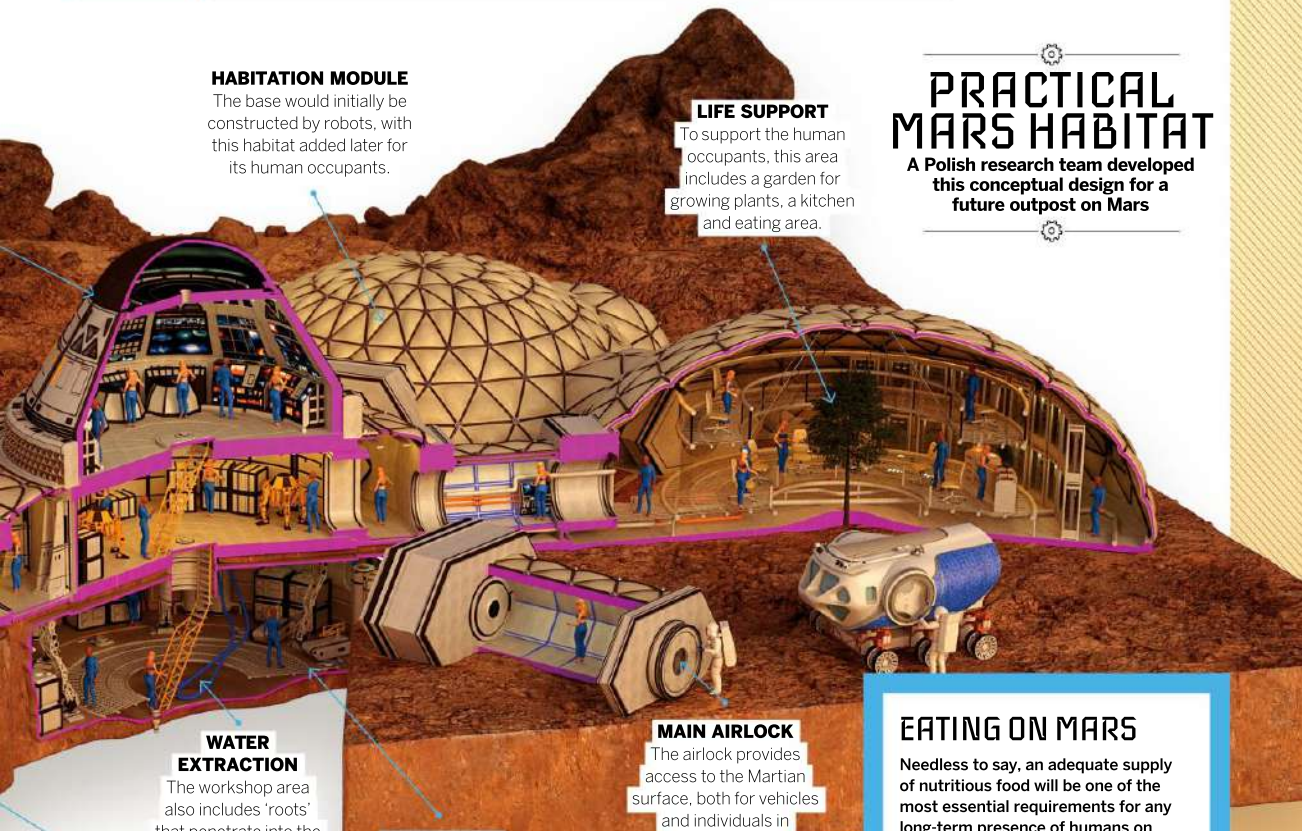
2037
By this time numerous Starships will be landing on Mars, fully loaded with hundreds of colonists and wealthy tourists.

Early 2040s
Mars Base Alpha will start to resemble a real city, with shops, hotels and even schools for children born there.

DID YOU KNOW? A 2012 remake of *Total Recall* cut out all the Martian scenes... and flopped at the box office

PRACTICAL MARS HABITAT

A Polish research team developed this conceptual design for a future outpost on Mars



HABITATION MODULE
The base would initially be constructed by robots, with this habitat added later for its human occupants.

LIFE SUPPORT
To support the human occupants, this area includes a garden for growing plants, a kitchen and eating area.

WATER EXTRACTION
The workshop area also includes 'roots' that penetrate into the Martian bedrock to extract water.

MAIN AIRLOCK
The airlock provides access to the Martian surface, both for vehicles and individuals in pressure suits.

COURTYARD AREA
Excavated into the sloping Martian terrain, this serves as a workshop area and storage space for vehicles.

INFLATABLE MODULES
The structure is gradually built up using a series of inflatable modules and connecting corridors.

AR zone SCAN HERE

EATING ON MARS

Needless to say, an adequate supply of nutritious food will be one of the most essential requirements for any long-term presence of humans on Mars. NASA has already experimented with food production on the International Space Station, with astronauts successfully growing lettuce and other plants there using the 'Veggie' plant-growth system. It's hoped that the same system can be expanded for use in future Mars missions, both en route to the Red Planet and while astronauts are living there. Besides the obvious physical importance of a food source, NASA believes that growing plants has psychological benefits too, acting as a way to relieve stress via gardening.

Food could be grown on Mars in scaled-up versions of NASA's Veggie system

2060s
By now some Mars-born humans will be travelling back to Earth for their vacations, supported by exoskeletons against the higher gravity.

2070s
All the spacefaring nations will likely have a presence on Mars, with half a dozen large cities spread over the planet.

2080s
Mars will have a well-established, self-supporting economy based around tourism, scientific research, mining and heavy industry.

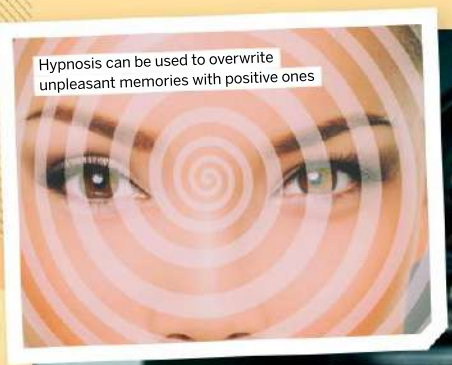
2099
By the end of the century Mars will be a self-sufficient, self-governing colony with a population in excess of a million.

© NASA / SpaceX / Alamy / Illustration by Nicholas Forder

Creating FALSE MEMORIES

The starting point for *Total Recall* is the idea that fake memories can be implanted in a person's brain, such as memories of an exotic holiday they never actually had. This isn't as far-fetched as it sounds, because memory isn't as cast iron as we think. Only a fraction of our experiences get filed away as long-term memories, and these have a tendency to distort slightly each time we remember them. It's even possible to convince people they had completely fictitious experiences, which they then recall just like real memories.

For example, if a friend 'reminds' you that you had a flight in a hot-air balloon and shows you a doctored photograph of the occasion, you may become convinced you remember it even though it never happened. Also, patients who suffer anxiety due to unpleasant memories can have those memories swapped for pleasant ones through hypnosis.



Hypnosis can be used to overwrite unpleasant memories with positive ones

In *Total Recall*, the process of implanting memories involves a rather daunting machine

ANIMAL MEMORY EXPERIMENTS

Psychological techniques aside, the actual physical modification of memories inside the human brain at a cellular level is still a long way off. Nevertheless, some of the basic principles have been demonstrated on laboratory animals. In 2012, for example, scientists at an American university used chemical injections and a laser beam to 'copy' a mouse's memory of receiving an electric shock inside one box to its memory of being inside another totally harmless box. The poor mouse then froze in terror when it was put inside the harmless box. In a later experiment, researchers at another university used RNA – a complex molecule related to DNA – to transfer memories from one sea snail to another.

Scientists have succeeded in implanting false memories in a laboratory mouse

Did you know?
Bad memories stick better than good ones

MEMORY TRANSPLANT

A 2018 experiment at the University of California involving RNA exchange between sea snails showed that memory transfer is possible

1 ELECTRIC SHOCK
Mild electric shocks have been applied to this snail's tail, which it 'remembers'.

2 TRAINED SNAIL
Because it remembers the shocks, the snail contracts whenever its tail is touched, even if no shock is applied.

3 RNA TRANSFER
RNA from the trained snail is injected into the untrained one.

SENSORY NEURONS

4 UNTRAINED SNAIL
This snail has never received an electric shock, so it doesn't mind its tail being touched.

INCREASED NEURON EXCITABILITY

5 FALSE MEMORY
The second snail now 'remembers' the shocks received by the first snail, so it contracts when its tail is touched.

Memories were transplanted into *Aplysia californica*, the California sea hare

5 FACTS
THE SCIENCE OF *TOTAL RECALL*

1 INTERPLANETARY ETHICS DILEMMA
If simple life forms exist on Mars – even ones we can't detect – we risk destroying them by visiting Mars and adapting it to our needs. Some people say this is unethical.

2 IMPERATOR OF MARS
That's the tongue-in-cheek title that SpaceX CEO Elon Musk devised for himself in April 2021. He believes his company is capable of landing humans on Mars within ten years.

3 BULGING EYEBALLS
When exposed to the Martian atmosphere, characters are shown being inflated by their own internal pressure. This is scientifically accurate – the atmosphere is too thin to support an unprotected human.

4 RADIATION MUTANTS ON MARS
In the film, radiation causes numerous bizarre mutant births, but radiation is much more likely to make people sick; any mutations would be so mild they probably wouldn't be noticeable.

5 MEMORY STORAGE UNIT
Human memory is stored in different parts of the brain, with short-term memories in the prefrontal cortex and long-term memories in the hippocampus deeper inside the brain.

© Alamy / Getty / US National Institutes of Health / Illustration by Ed Crooks

TESTING HAWKING'S THEORIES

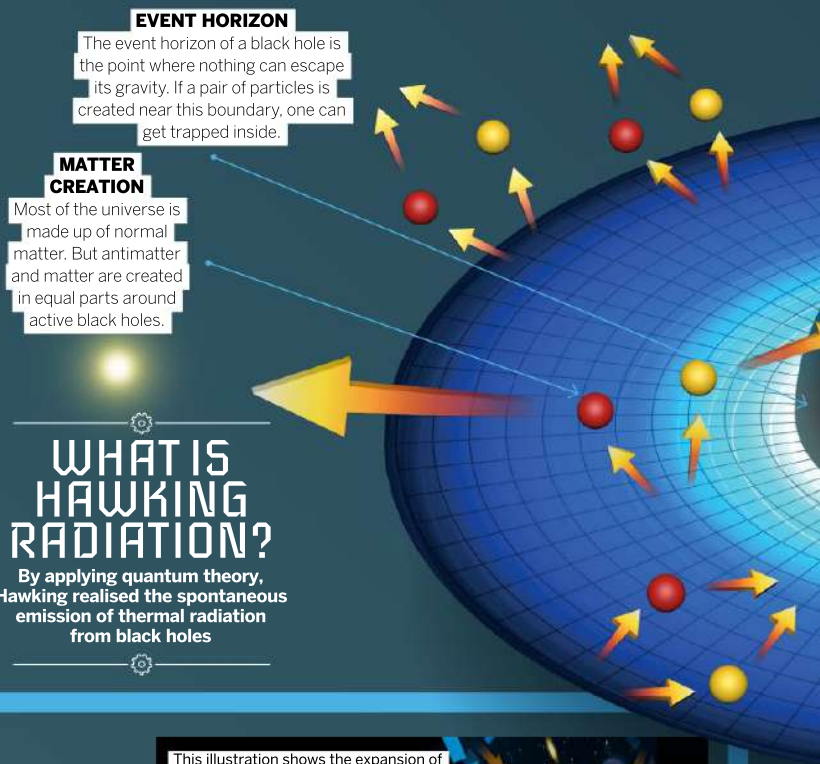
Which of Stephen Hawking's explanations turned out to be right?

WORDS ANDREW MAY

Stephen Hawking was one of the greatest theoretical physicists of the modern age. Otherwise known for his appearances in popular media and his lifelong battle against a debilitating illness, his true impact comes from his brilliant five-decade career in science. Beginning with his doctoral thesis in 1966, his groundbreaking work continued nonstop right up until his final paper in 2018, completed just days before his death at the age of 76.

Hawking worked at the intellectual cutting edge of physics, and his theories often seemed bizarrely far out at the time he formulated them. Yet they're slowly being accepted into the scientific mainstream, with new supporting evidence coming in all the time. From his mind-blowing views of black holes to his explanation for the universe's humble beginnings, here are some of his theories that were vindicated, and others that are still up in the air.

Hawking presenting a lecture at George Washington University in 2008


EVENT HORIZON
The event horizon of a black hole is the point where nothing can escape its gravity. If a pair of particles is created near this boundary, one can get trapped inside.
MATTER CREATION
Most of the universe is made up of normal matter. But antimatter and matter are created in equal parts around active black holes.

WHAT IS HAWKING RADIATION?

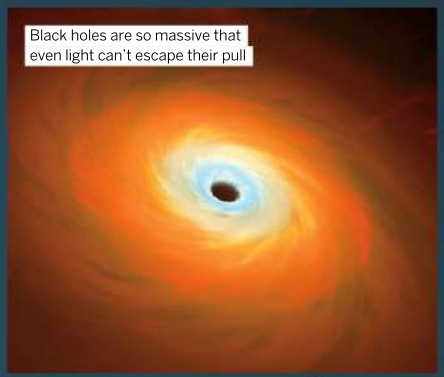
By applying quantum theory, Hawking realised the spontaneous emission of thermal radiation from black holes

THE BIG BANG WINS

Hawking got off to a flying start with his doctoral thesis, written at a critical time when there was a heated debate between two rival cosmological theories: the Big Bang and steady-state. Both theories accepted that the universe is expanding, but in the first it expands from an ultra-compact, super-dense state at a finite time in the past, while the second assumes the universe has been expanding forever, with new matter always being created to maintain a constant density. In his thesis, Hawking showed that steady-state theory is mathematically self-contradictory. He argued instead that the universe began as an infinitely small, infinitely dense point called a singularity. Today, Hawking's description is almost universally accepted among scientists.

This illustration shows the expansion of the universe, starting at the Big Bang around 13.8 billion years ago

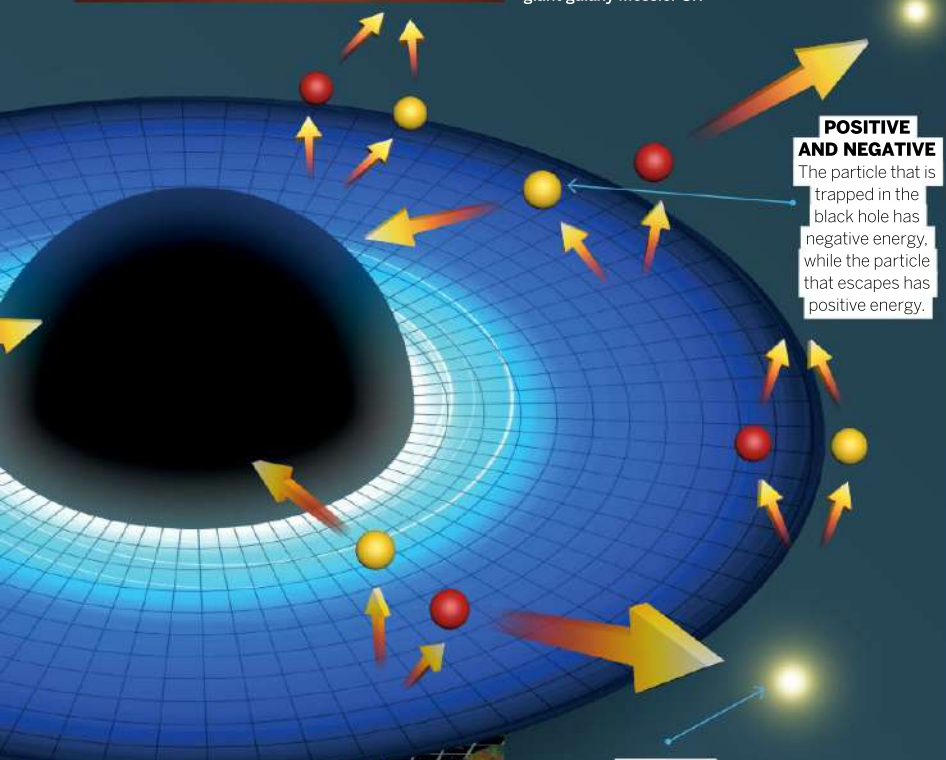
DID YOU KNOW? Hawking wrote books that explained his theories in simple terms so that his work wasn't limited to scientists



Black holes are so massive that even light can't escape their pull

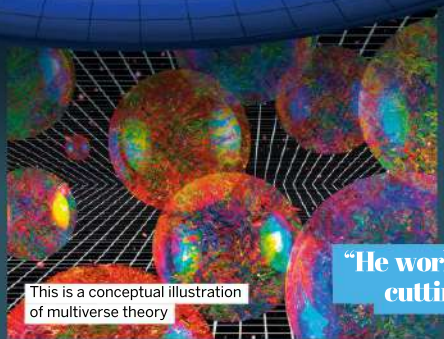
BLACK HOLES ARE REAL

More than anything else, Hawking's name is associated with black holes – another kind of singularity, formed when a huge star undergoes complete collapse under its own gravity. These mathematical curiosities arose from Einstein's theory of general relativity, and they had been debated for decades when Hawking turned his attention to them in the early 1970s. His stroke of genius was to combine Einstein's equations with those of quantum mechanics, turning what had previously been a theoretical abstraction into something that looked like it might actually exist in the universe. The final proof that Hawking was correct came in 2019, when the Event Horizon Telescope obtained a direct image of the supermassive black hole lurking in the centre of giant galaxy Messier 87.



POSITIVE AND NEGATIVE
The particle that is trapped in the black hole has negative energy, while the particle that escapes has positive energy.

HAWKING RADIATION
The particle of the pair that hasn't been trapped in the event horizon is emitted from the black hole as Hawking radiation.



This is a conceptual illustration of multiverse theory

"He worked at the intellectual cutting edge of physics"

AR zone
SCAN HERE

5 THEORIES SCIENTISTS ARE UNSURE ABOUT

1 INFORMATION PARADOX
Hawking believed that information about the basic properties of the material that made a black hole is stored in a cloud of zero-energy particles surrounding it. This is one of several hypotheses that have been put forward about black holes' lost material.

2 PRIMORDIAL BLACK HOLES AND DARK MATTER
Hawking was the first person to explore the theory behind black holes that were created soon after the Big Bang in depth. He said that these black holes might make up the mysterious dark matter that astronomers believe permeates the universe.

3 THE MULTIVERSE
Hawking wasn't happy with the suggestion made by some scientists that any ludicrous situation you can imagine must be happening right now somewhere in one of an infinite number of universes. Instead he proposed a novel mathematical framework that rendered the universe finite.

4 CHRONOLOGY PROTECTION CONJECTURE
Hawking was bothered by the fact that Einstein's equations allowed backward time travel because he felt that it raised logical paradoxes that shouldn't be possible. He suggested that some currently unknown law of physics prevents these 'closed timelike curves' from occurring – his so-called 'chronology protection conjecture'.

5 DOOMSDAY PROPHECIES
In his later years, Hawking made a series of bleak prophecies concerning the future of humanity that he may or may not have been totally serious about. These range from the suggestion that the elusive Higgs boson might trigger a vacuum bubble that would gobble up the universe to hostile alien invasions and artificial intelligence (AI) takeovers.

© Getty / Illustration by Adrian Mann

HOW BABIES ARE MADE

The fusion of sex cells that begins the great journey of pregnancy

WORDS JAMES HORTON

A sperm cell must pass a thick membrane encasing the egg, known as a zona pellucida, before fertilisation can occur

Did you know?
A female baby is born with a lifetime supply of eggs

Humans reproduce by sexual reproduction. This mixes the genetic information of two people. For this to happen we have evolved specialised sex cells, known as gametes, that are specific to each sex. Females produce and carry egg cells that, much like their vastly larger avian equivalents, contain both genetic information and form the nexus of an embryo. Females also have a dedicated sex organ called a uterus, which nurtures the embryo during its development. Males provide the other half of the genetic information by producing sperm cells.

Both the egg and sperm hold instructions encoded by deoxyribonucleic acid (DNA), which contains all the information needed to form a functional human body. The cells' DNA is wrapped up tightly into large structures called chromosomes. Both the egg cell and the sperm cell carry 23 chromosomes, which once aligned in an embryo will form 23 pairs that will be carried by every somatic cell in a mature human body. Two of these chromosomes form a pair known as sex chromosomes, as they define the sex of the baby during development. Every egg cell carries an X chromosome, and a sperm cell can carry either an X or a Y chromosome. Females are encoded by a combination of XX, and males by a combination of XY. Our genetic sex is sealed the very moment our two sets of chromosomes meet during fertilisation.

Fertilisation can begin once an egg is released by a follicle in the ovaries, a step that occurs periodically in women of fertile age. Throughout this cycle, stages of hormones trigger the release of an egg, which in turn triggers more signals intended for the wall of the uterus, which thickens in expectation of a fertilised embryo to implant in its surface. This offers a brief window of time for legions of sperm to be released from a male's testicles and undertake the long, arduous journey through a female's uterus to reach the egg while it is viable.

The fusion between a sperm and egg cell's DNA marks the beginning of embryo development, and once it has found its home in the nourishing lining of the uterine wall, the embryo undergoes a monumental growth spurt. It transforms from a mere bundle of cells into a foetus, acquiring a heart, brain, jaw, fingers and toes. Within the first 12 weeks of pregnancy the foetus boasts a full complement of organs. This incredible metamorphosis is guided on a cellular level by genetic instructions encoded within the DNA and by external environmental signals. These signals tell the cells how to interact with one another, where to migrate, how to divide and when to die to make way for new cells. This allows a swarm of microscopic cells to differentiate and develop into something not only gargantuan in size but also in complexity: a fully formed human baby.

THE GENESIS OF LIFE

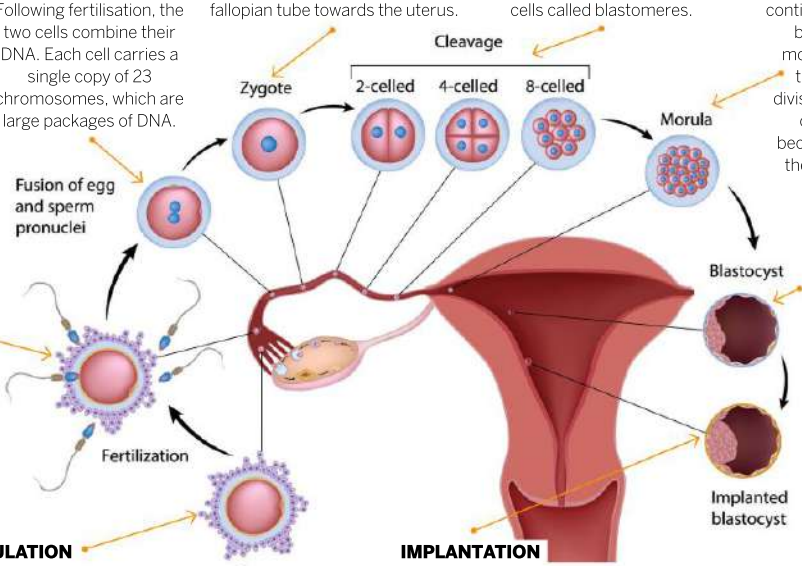
The steps that bring together DNA from parents and initiate pregnancy

X MEETS Y, OR X
Following fertilisation, the two cells combine their DNA. Each cell carries a single copy of 23 chromosomes, which are large packages of DNA.

UNION
A fertilised cell with a full complement of 23 pairs of chromosomes forms a zygote, which migrates through the fallopian tube towards the uterus.

CLEAVAGE
As the fertilised cell migrates towards the uterus it undergoes cleavage, dividing from a single cell into a connected cluster of cells called blastomeres.

MORULA
The berry-like configuration of blastomeres continues to divide, becoming a morula. During these latter divisions the cells commit to becoming either the embryo or placenta.



FERTILISATION
For 12 to 24 hours after it's released, an egg can be fertilised by a sperm cell that has successfully traversed the fallopian tube.

BLASTOCYST
A cavity of fluid builds between the inner cell mass, which will become the embryo, and the outer cells, which will help form the nourishing placenta.

OVULATION
A mature egg cell, known as an ovum, is periodically released from a female's ovaries as part of the menstrual cycle.

IMPLANTATION
The blastocyst adheres to the wall of the uterus, known as the endometrium, which helps nourish the embryo throughout its development.

© Alamy / Getty / Science Photo Library

IN VITRO FERTILISATION

The process of fertilisation and embryo implantation is a wonderfully elegant yet complex process. This complexity, however, presents numerous opportunities for natural obstacles and barriers that prevent natural conception. Such obstacles include damage or blockage of the fallopian tubes, which can prevent the sperm and egg meeting or the fertilised egg from reaching the uterus. Other disorders affect the release of eggs from the ovaries, and others affect males by reducing sperm number and activity. These challenges have driven the development of in vitro fertilisation (IVF), which offers a human-made bridge to pregnancy when the natural path is blocked. IVF is a process whereby the act of fertilisation, initial embryo division and implantation are conducted in the laboratory under the guidance of scientists.

IVF allows scientists to microscopically examine and genetically screen embryos for abnormalities before implantation

SPERM INJECTION

Males with semen that contains millions of healthy and active sperm cells per millilitre are often able to achieve fertilisation organically. But semen harbouring a low sperm count, irregular-shaped sperm or sperm that aren't particularly mobile can find it difficult, or even impossible. Sperm injection provides an alternative means to achieve fertilisation. Clinicians can use micropipettes to hold the egg in place and directly inject sperm cells into the egg using a micro-sized needle, allowing the sperm cell to reach its goal.

Tiny needles can be used to penetrate the egg and directly inject sperm

Louise Brown, pictured with her parents Lesley and John, was the first baby born through IVF

THE WORLD'S FIRST 'TEST TUBE' BABY

In 1977, Lesley Brown – who was struggling with infertility due to blocked fallopian tubes – was put in contact with scientists Dr Robert Edwards and Dr Patrick Steptoe. Steptoe was an expert in obtaining eggs from ovaries and Edwards an expert in fertilising human eggs in a petri dish. Together the two offered Lesley Brown the opportunity – albeit one with a slim chance of success – to artificially fertilise her eggs with her husband's sperm. Without the use of hormones to manipulate her natural menstrual cycle and increase egg production, the scientists overcame the odds and successfully performed the first in vitro fertilisation and implantation of a single lab-fertilised embryo.

Did you know?
The first 'three-parent' baby was born in 2016

FERTILISATION IN A LABORATORY

The artificial fertilisation technique that helps parents overcome natural barriers to conception

1

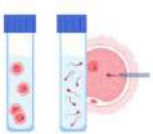
INCREASING EGG SUPPLY

Hormones are administered which suppress the natural menstrual cycle. These are followed by fertility hormones that boost egg production by the ovaries.

2

COLLECTION AND FERTILISATION

Eggs are collected using a needle inserted into each ovary and fertilised with sperm by either mixing or directly injecting the sperm into the egg.



3

EMBRYO DEVELOPMENT

The embryo is stored in an incubator and begins to divide. Many clinics wait until the cell has divided into a blastocyst before implantation.

4

GENETIC SCREENING

DNA from a single or small number of cells is removed from the embryo and tested for abnormalities.

5

CRYOPRESERVATION

Healthy embryos that will not be implanted immediately can be frozen and stored safely for years for later implantation.

6

EMBRYO TRANSFER

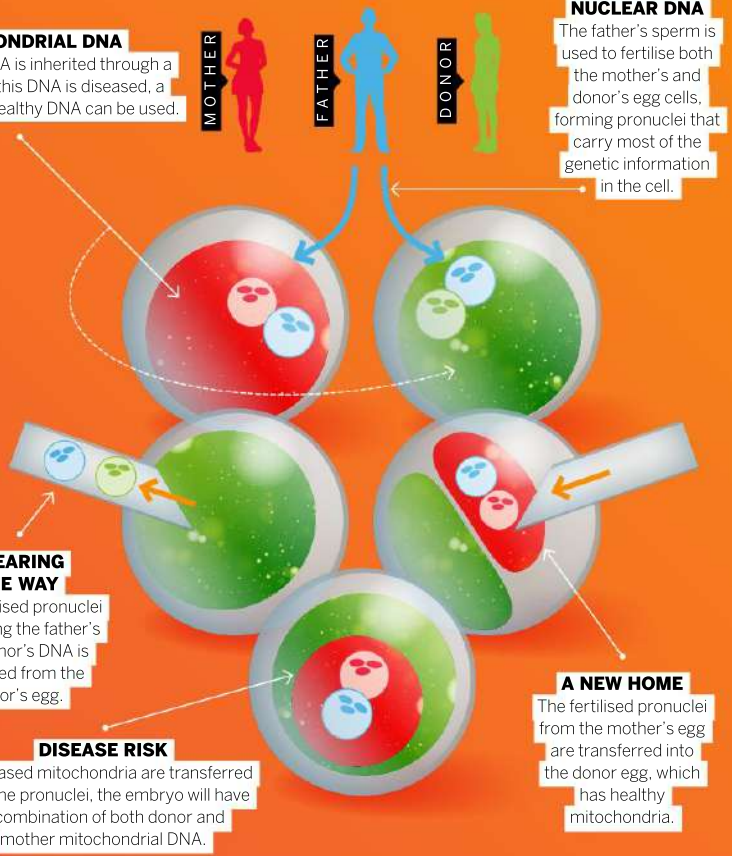
The embryo is implanted in the uterus using a flexible tube called a catheter, which is carefully guided into place using an ultrasound scan.

DID YOU KNOW? Embryologists select 'good' embryos based on how well the embryo divides and how many chromosomes the cells have

ONE BABY, THREE PARENTS

ROOM FOR ONE MORE

Replacing a mother's diseased mitochondrial DNA allows a baby to carry genes from three people

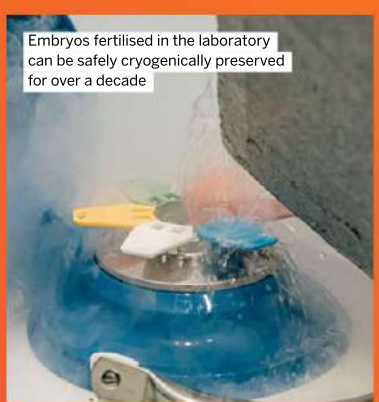

MITOCHONDRIAL DNA
Mitochondrial DNA is inherited through a mother's egg. If this DNA is diseased, a donor's egg with healthy DNA can be used.
MOTHER
FATHER
DONOR
NUCLEAR DNA
The father's sperm is used to fertilise both the mother's and donor's egg cells, forming pronuclei that carry most of the genetic information in the cell.
CLEARING THE WAY
The fertilised pronuclei containing the father's and donor's DNA is removed from the donor's egg.
DISEASE RISK
If diseased mitochondria are transferred with the pronuclei, the embryo will have a combination of both donor and mother mitochondrial DNA.
A NEW HOME
The fertilised pronuclei from the mother's egg are transferred into the donor egg, which has healthy mitochondria.

Nuclear DNA resides inside the nucleus of our cells. This DNA is huge, composed of reams of instructions 3.3 billion base pairs in length. Nuclear DNA comes from both our mother and father and is responsible for the vast majority of characteristics we display as we develop. However, our cells also host a small chunk of independent DNA that lives inside cellular components called mitochondria, which are energy-producing factories that power our cells. Mitochondrial DNA comes solely from our mother and is inherited from the fertilised egg cell at the beginning of gestation.

Mitochondrial DNA is miniscule in length compared to its nuclear counterpart, measuring around 16,500 base pairs in length, and contains instructions only for the function of mitochondria. In rare cases a mother can harbour a catastrophic mutation in this DNA that prevents healthy embryos developing. To circumvent this problem, scientists have developed a technique that combines nuclear DNA from two genetic parents with mitochondrial DNA from a donor. This removes the risk of inheriting mitochondrial diseases and means that the birthed baby will forever carry DNA from three people.

Three-parent babies have nuclear DNA from their mother and father and mitochondrial DNA from a donor

Physiologist Robert Edwards (left) and gynaecologist Patrick Steptoe (right) were the forerunners of successful IVF treatment



Embryos fertilised in the laboratory can be safely cryogenically preserved for over a decade

© Alamy / Getty

Embryonic stem cells have the potential to become any cell type

THE SCIENCE OF STEM CELLS

A fertilised embryo that nestles into the uterine wall holds mammoth amounts of potential. The cells destined to become a foetus at that moment all look alike and number in the mere hundreds. Yet the organism that will arise from this small enclave will one day boast trillions of cells and be composed of a plethora of specialist cell types. How can the multitude of different cell types that make up our eyes, brain, lungs and skin come from such a small number of similar cells? The answer to this exponential increase in complexity and specialisation comes from stem cells.

Every cell in the human body contains all the genetic information needed to perform any role. But for our bodies to develop and function efficiently, we need skin cells to behave like skin, and for muscles to behave like muscles. For this to happen our cells become specialised, or differentiated, into particular cell types, meaning they only use a part of the genetic information available in their DNA.

However, all cell types begin their existence as stem cells, undifferentiated cells that have the potential to become many different cell types. Embryonic stem cells are there at the origin of our developmental journey. As the embryo grows and develops into a foetus, chemical signals received by the stem cells begin their journey of differentiation, sealing their fate to become certain cells by silencing and unlocking specific parts of their DNA.

Did you know?
Activating just four genes can revert specialised cells

The malleable power of stem cells also represents remarkable opportunities for those who can harness them. As well as being able to recover embryonic stem cells from early embryos, recent advances have discovered the cellular signals needed to convert differentiated cells back into their unspecialised states. This provides multiple means for scientists to take a cell and transform it into any cell type of their choosing. Research is underway to grow entire transplant organs for a patient from their own cells, and we can even utilise stem cells to generate egg and sperm cells that give rise to new life.

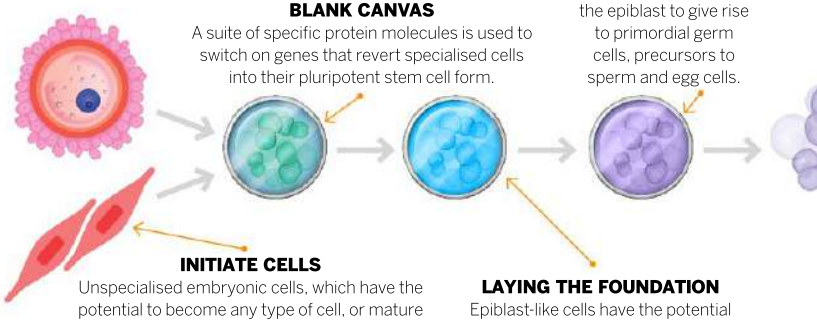
CLONING

The egg cell is essential, designed to ensure that the encoded DNA in the nucleus develops into an embryo. But scientists wondered if the egg could only drive the embryonic development of DNA from both parents, or if it could transform any nuclear DNA into an embryo. In the 1960s they started to find out. Beginning with frog cells, as they're large and easier to manipulate, scientists removed the nuclear DNA from a fertilised egg and replaced it with nuclear DNA from an intestinal cell of an adult frog. After around 40 days, the result was a tadpole that was genetically identical to the frog that had donated the intestinal cell, as all the nuclear DNA had come from one animal.

Dolly the sheep was the first mammal successfully cloned

ENGINEERING AN EGG FACTORY

How an embryo or a mature specialised cell can be transformed into a fertilisable egg



BLANK CANVAS
A suite of specific protein molecules is used to switch on genes that revert specialised cells into their pluripotent stem cell form.

PROGENITOR
Cellular signals cause the epiblast to give rise to primordial germ cells, precursors to sperm and egg cells.

INITIATE CELLS
Unspecialised embryonic cells, which have the potential to become any type of cell, or mature specialised cells, can be used for the process.

LAYING THE FOUNDATION
Epiblast-like cells have the potential to become many different cell types.

DID YOU KNOW? Cloned animals are used in farming in the US to help preserve desirable genes for breeding

Polejaeva studies the production of transgenic cloned animals for use in agriculture and biomedicine

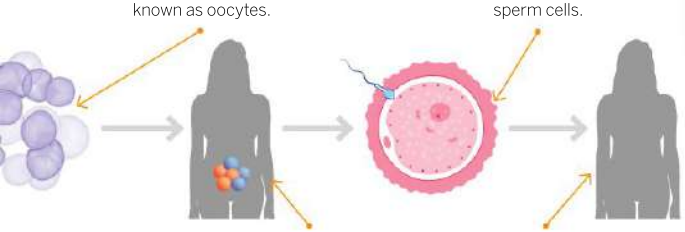
THE ADVANTAGES OF CLONING

World expert Professor Irina Polejaeva discusses cloning in the agricultural industry

"One key benefit of cloning is that it allows you to introduce specific traits over just one generation. A desired trait may be caused by a specific DNA change and only be naturally present in one breed of cattle and lacking in another. However, we can design clones so that they have attributes from both breeds. For example, horn growth in dairy cattle can be a danger to other animals and those that care for the animals. To induce a lack of horns through a genetic path, you'd usually need to go through multiple generations of breeding, but alternatively we can edit the gene in cells prior to cloning to get this trait immediately. This helps to improve animal welfare as we can avoid farming practices like the dehorning procedure, which is when a calf's horn buds are burned to prevent them growing."

SUPPORTIVE SCAFFOLDING
The germ cells are aggregated with ovarian tissue, which helps the cells specialise into premature eggs known as oocytes.

IN VITRO FERTILISATION
The specialised egg cell is removed from the host and fertilised in the laboratory with sperm cells.



A NATURAL SETTING
The aggregated cells are implanted into a host's ovary, which enables their continued growth and maturation.

GESTATION BEGINS
The once-specialised cell has become part of a fertilised embryo, which is implanted into a donor for gestation.

EMBRYO GROWTH

What allows embryos to develop such complex structures? We speak with Dr Megan Davey to find out

Davey is a group leader at the Roslin Institute, where she researches chicken embryos to study limb development

The development of an embryo is an amazingly complex phenomenon. Can you outline some of the major proteins involved in driving this process?
One of the main proteins responsible for limb patterns and growth is known as the Sonic hedgehog (SHH) protein. For SHH to work correctly, it has to come on for exactly the right amount of time and have exactly the right amount of activity. If you lose the activity of this protein, embryos develop with unusual differences. Too much can cause too many fingers to form; too little and things like cyclopia, where the eyes don't part and the nose doesn't develop properly, can occur. Another important protein is TALPID3, which affects the activity of centrosomes, cellular structures that are important for cell division. When the cell is not dividing, the centrosome migrates up to the cell surface and docks onto the cell membrane. Cells use centrosomes as their compass, but cells that lack the TALPID3 protein lose their spatial awareness. Centrosomes in these cells continue to migrate, but they don't migrate in the right direction. Instead they move all over. This means that cells can end up growing the wrong way.

Could investigating stem cell activity lead to any medical applications?
We currently don't know how to regenerate fingers, and we don't know if there's a stem cell for regenerating fingers. My hypothesis is that embryos may have stem cells at the tips of their growing digits. We're currently investigating useful genetic tools in chickens, and one that we're developing is called the Brainbow chicken, which allows us to visually mark cells and see where they go during development. We can use this to label the cells found at the end of the digits and see if they behave like stem cells, allowing us to learn more about how to regenerate fingers.

Chicken embryos can be filmed under a microscope to track how embryos develop their limbs

© Getty / Alamy / Roslin Institute, University of Edinburgh / Irina Polejaeva / Megan Davey, Roslin Institute

SHAMPOO SCIENCE

What chemical processes occur within the foaming lather of shampoo?

WORDS AILSA HARVEY

Leaving hair unwashed for multiple days can cause it to feel heavy and greasy. This is because the scalp is continuously producing a natural oil called sebum. Without this sebum shield, the proteins within our hair would become damaged more easily. When there is a build-up of this oil and our hair is in need of a wash, water alone can't remove it very effectively.

Sebum largely resists mixing with water, especially if the water is cool, but when the water combines with shampoo it targets the oil. Molecules in shampoo called surfactants work to produce a frothy lather. They have two polar ends – one being hydrophobic (repelled by the water) and one being hydrophilic (attracted to the water). When rubbed into hair with both water and oil, the grease and dirt is carried off hair and down the drain.

DIFFERENT QUALITIES FOR ALL HAIR TYPES

Anti-frizz shampoo often contains added silicones to make hair smoother. To achieve this, silicones act as a barrier against moisture. This stops hair from drying out, as well as preventing humid weather contributing to frizziness. Shampoos with more silicones aren't recommended for fine hair, as the weight they add can cause strands to break. Medical products like anti-dandruff shampoo contain ingredients to soothe discomfort experienced on the scalp and target more specific scalp issues. For dandruff sufferers, pyrithione zinc can be added to kill the *Malassezia* yeast that causes the condition.

Hairdressers use different shampoo types based on a customer's needs

DID YOU KNOW? Before shampoo, vegetable starch or wood ash could be rubbed into hair to absorb grease

WHAT DO YOU PUT ON YOUR HAIR?

These are the basic ingredients of shampoo

10-20%
SURFACTANTS
These ingredients lower the surface tension between oils and water, allowing the shampoo to bind with grease and remove it during washing.

0.3-0.5%
FRAGRANCE
Multiple ingredients can be added to create the smell of your shampoo. These may include natural chemicals such as menthol or synthetically produced fragrances such as jasmine-smelling amyl cinnamal.

1%
PRESERVATIVES
Ingredients such as sodium benzoate, potassium sorbate or sorbic acid prevent bacteria from growing in the bottle.

2%
CONDITIONERS
To retain natural oils in the hair, conditioning substances such as glycerin attract any surrounding moisture.

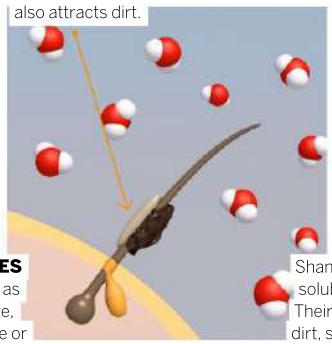
2%
THICKENERS
Alcohols, carnauba wax and xanthan gum are among common shampoo thickeners. These help create the shampoo's flow and consistency.

75-80%
CARRYING AGENTS
The majority of shampoo's content is water. This helps to activate the other ingredients by binding cleaning agents to oil.

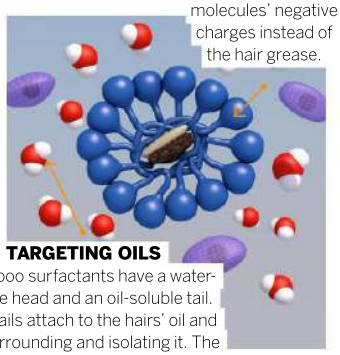
THE CLEANING PROCESS

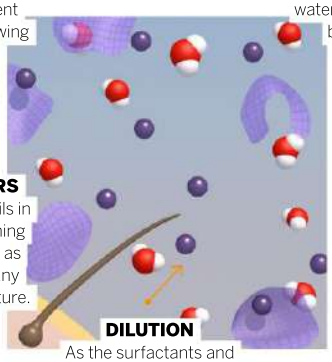
Take a close-up look at the chemistry of a hair wash

OILY BUILD-UP
The scalp produces a waxy substance called sebum; this stops hair from drying out but also attracts dirt.

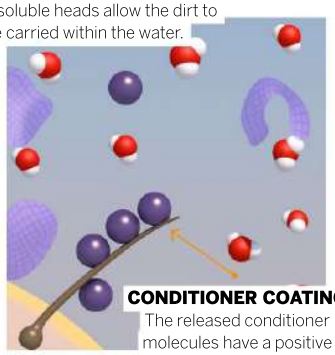


TARGETING OILS
Shampoo surfactants have a water-soluble head and an oil-soluble tail. Their tails attach to the hairs' oil and dirt, surrounding and isolating it. The water-soluble heads allow the dirt to be carried within the water.





DILUTION
As the surfactants and dirt are washed away, the bond between conditioner molecules and their fatty acid coating weakens.



CONDITIONER COATING
The released conditioner molecules have a positive charge and are drawn to the clean hair. This forms a moisturising coating.

ISOLATED CONDITIONERS
Conditioner molecules are positively charged, so they attract a fatty acid coating. This stops them from binding with the shampoo molecules' negative charges instead of the hair grease.

Overwashing hair can make it too dry. Sebum glands can respond by producing extra oil and making hair greasier

© Getty / Alamy / Illustration by Adrian Mann

THE WONDER OF WATER

How this vital liquid has shaped our world, fostered life and travelled beyond Earth

WORDS **BALJEET PANESAR**

From the creatures at the bottom of the ocean to the mighty elephant, all living things require water; it's one of the essential requirements for life, on Earth and beyond. It's the world's most precious resource, but most of us take it for granted since it flows from our faucets, falls from the sky and covers most of the planet.

The average person uses around 142 litres of water per day. We use water for everything: cooking, drinking, washing, growing our food and in industry and construction. Without this precious liquid we wouldn't be able to survive for more than a few days. Most of your body is made up of water, too, and this changes during your lifetime. When we're born our bodies are made up of around 78 per cent water, but as we age the water in our bodies decreases, reducing to around 60 per cent in adulthood.

Every water molecule on Earth, including those inside you, has existed here for most of Earth's 4.5-billion-year history. Only a tiny bit of it has escaped into space, and no new water has been made. This means that the water you're drinking today is some of the same water that thirsty dinosaurs were drinking 65 million years ago.

This is because all of Earth's water is constantly recycled in a process that's known as the water cycle. In this process, water from a lake, ocean or river warms up, changing into a gas (water vapour) as it travels into the atmosphere. When water vapour in the air cools down it turns back into tiny droplets of liquid water, forming clouds. The clouds eventually get too heavy, releasing water back onto land in the form of rain, snow, sleet or hail. The rain water collects in lakes, rivers and oceans, and the cycle starts all over again.

Above: A 3D illustration of the molecular composition of water: hydrogen and oxygen

Opposite: This image of Europa was constructed from data collected by the Galileo satellite during its flyby of the Jupiter moon in 2000

Although water may be all around us, this precious commodity isn't evenly distributed around the world. Of the 7.8 billion people in the world, around 884 million people – that's around one in nine people – don't have access to safe drinking water, and 114 million people drink untreated surface water from lakes, rivers and streams, exposing themselves to diseases like cholera, dysentery, polio and typhoid fever. Contaminated drinking water is estimated to cause 485,000 diarrhoea-related deaths each year. By 2050, it's estimated that half the world's population won't have access to safe drinking water due to climate change and other factors.

"Without this precious liquid we wouldn't be able to survive for more than a few days"

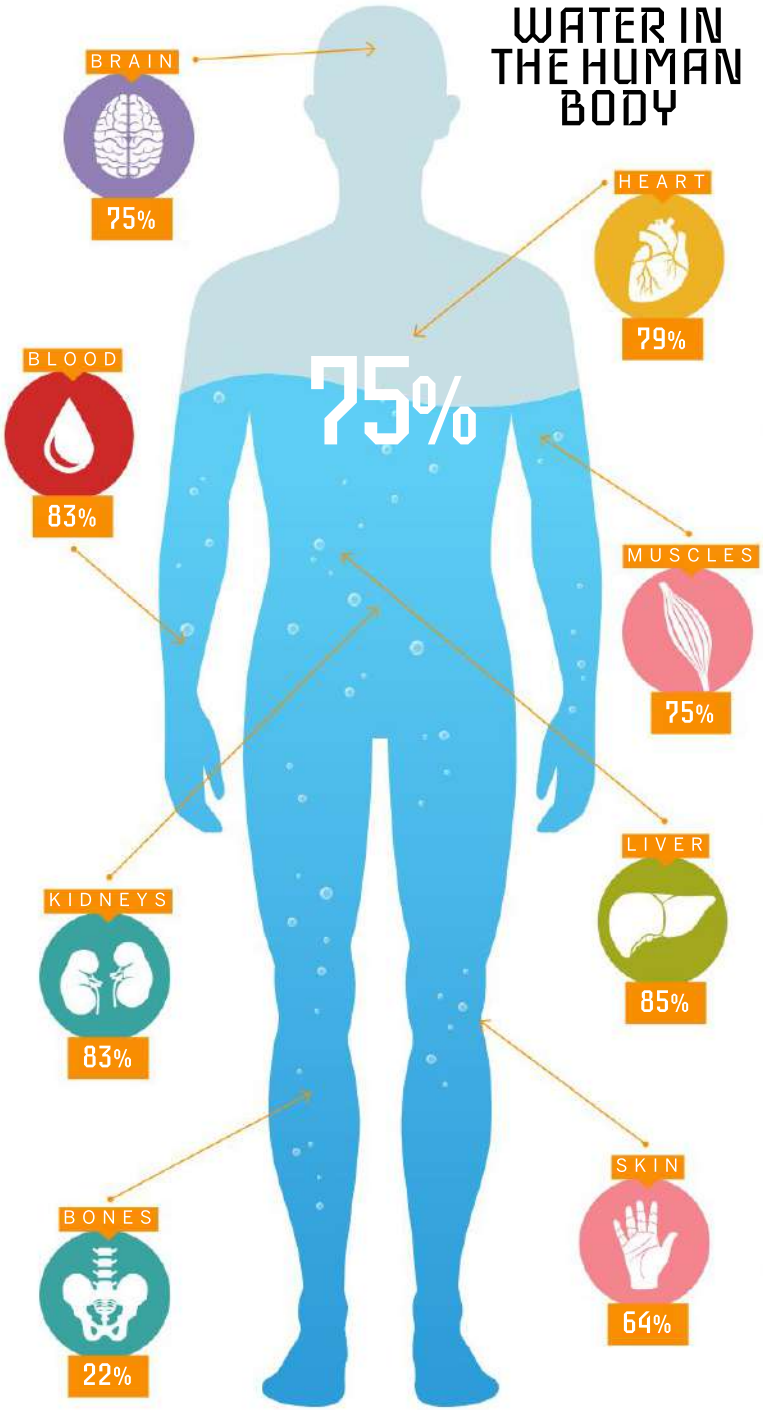
WATER IN SPACE

Water isn't just found on Earth but throughout our Solar System. Water in the form of liquid subsurface oceans, ice or vapour exists on several worlds, including the Moon, Mars and the moons Ganymede, Titan and Enceladus. Water is found in comets and asteroids, the leftovers from the formation of the Solar System some 4.5 billion years ago, and dwarf planets Pluto and Ceres. Finding water on other worlds will help in the search for life beyond Earth. One of the most promising targets is Jupiter's moon Europa. This icy moon has all the ingredients for life: water, chemistry and energy. Europa's subsurface ocean contains twice as much water than all the water in Earth's oceans.

FASTER TRAVEL

Sound waves travel as air particles and bump into each other as they vibrate, causing other nearby air particles to vibrate too. In water, particles are much closer together, so the vibration energy can be transferred much more quickly. The speed of sound in air is 343 metres per second, while in water it's around 1,432 metres per second, roughly four-times faster. However, it takes much more energy to start a sound wave in water because the wave needs more energy to force the water particles to move, but this means that sound waves can travel longer distances than in air.

WATER IN THE HUMAN BODY



© Getty / NASA/JPL-Caltech/SETI Institute

Win!

TWO INSTANT-PRINT CAMERAS

WORTH

£190

This month we're giving you the chance to win two myFirst Insta 2 cameras, the HD digital camera that instantly prints images taken with both the front and back lenses. In just ten seconds you can print out your favourite snaps, and you can edit them to feature one of the many preloaded picture frames. Thanks to its built-in thermal printing technology, there's no need to refill any ink for unlimited printing.

myFirst Insta Wi

Check out the HD camera with Inkless Printer and Label at **kickstarter.com**

For your chance to win, answer the following question:

On which continent would you find the South Pole?

A: EUROPE B: ANTARCTICA C: SOUTH AMERICA

Enter online at **howitworksdaily.com** and one lucky entrant will win!

Terms and Conditions: Competition closes at 00:00 BST on 21 October 2021. By taking part in this competition you agree to be bound by these terms and conditions and the Competition Rules: **www.futuretcs.com**. Entries must be received by 00:00 BST on 21/10/2021. Open to all UK residents aged 18 years or over. The winner will be drawn at random from all valid entries received, and shall be notified by email or telephone. The prize is non-transferable and non-refundable. There is no cash alternative.

© MyFirst

Special offer for readers in **North America**

4 FREE ISSUES

WHEN YOU SUBSCRIBE*

FREE
WIN
HOW IT WORKS
007's GADGETS
HOW JAMES BOND'S INCREDIBLE TOYS COMPARE WITH TODAY'S TECHNOLOGY
CLIMATE CHANGE: THEN & NOW
EXPLORE THE AMAZON OF THE OCEAN
AMAZING ALTERNATIVE WAYS OF MAKING A BABY
COULD WE BUILD TOTAL RECALL?
WORLD'S DEADLIEST VOLCANIC ERUPTIONS
THE STORY OF EARTH
12 UNBELIEVABLE INVENTIONS
ALL ABOUT YOUR DNA

"The action-packed science and technology magazine that feeds minds"

Order hotline **+44 (0) 330 333 1113**

Online at **www.magazinesdirect.com/hiw/79as**

***Terms and conditions** Offer closes 30/11/2021. Offer open to new subscribers only. Direct Debit offer is available to UK subscribers only. This price is guaranteed for the first 12 months, and we will notify you in advance of any price changes. Please allow up to six weeks for delivery of your first subscription issue, or up to eight weeks overseas. The full subscription rate is for 12 months (13 issues) and includes postage and packaging. If the magazine ordered changes frequency per annum, we will honour the number of issues paid for, not the term of the subscription. For full terms and conditions visit **www.magazinesdirect.com/terms**. For enquiries please call: +44 (0) 330 333 1113. Lines are open Monday to Friday 9am to 5pm UK time or e-mail: **help@magazinesdirect.com**. Calls to 0330 numbers will be charged at no more than a national landline call, and may be included in your phone provider's call bundle.

OFFER EXPIRES **30 NOV 2021**

Fusion reactors like this are set up to turn hydrogen into helium, releasing energy

MEET THE EXPERTS

Who's answering your questions this month?

Jo Elphick
History and forensic science

Andy Extance
Chemistry, tech and science

Andrew May
Space, transport and science

Victoria Williams
Animals, the environment and science

Could we make elements in a human-made fusion reactor?

Alan Mora

Today's fusion test reactors do generate energy by making an element. That element is helium. The test reactors take in a lot of energy to fuse together different types of hydrogen atoms, making helium and ideally releasing much more energy. But most test reactors don't often produce more energy than they use. These reactors just focus on making this hydrogen-to-helium process happen. That's not like stars, which can carry on fusing to make different elements. Scientists do try to make entirely new elements, but by smashing beams of atoms of different elements together rather than using a fusion reactor. AE

The control room of the Wendelstein 7-x fusion reactor in Germany shows hydrogen plasma being generated

DOES THE EMPEROR OF JAPAN STILL HAVE ANY POWER?

Alice Mayes

While the emperor is considered to be the head of state, in reality he has little in the way of power. He carries out a number of constitutional ceremonies, such as the opening of parliament, but he has no political powers and is forbidden from sharing any political opinions. **JE**

WHEN DID HUMANS START WEARING CLOTHES?

Jane Wentworth

Since clothing doesn't fossilise, it's very hard to track when humans first started wearing garments. The best estimate is 170,000 years ago, when some head lice started living in cloth. **JE**

Lambs and chicks have become icons of spring

Why are most animals born in spring?

Aaron Bowers

Spring has long been associated with new beginnings in temperate climates. This season gives young birds and mammals the best chance of survival, since extreme weather is less likely. Days are longer, giving parents of foraging species more time to find food, and there's an abundance of vegetation and insects. **VW**

Did you know?

Without a tilted axis, Earth wouldn't have seasons

Why is Earth's axis on a tilt?

@_rchiesw_in

When the Earth was formed, its spin axis would have been almost perpendicular to the plane of its orbit. The tilt you're talking about resulted from collisions with other objects early in Earth's history and may once have been even greater than the 23.5 degrees we see today. **AM**

© Alamy / Getty

CAN YOU PULL A HEART MUSCLE IF YOU EXERCISE TOO MUCH?

Athena Frost

In general, you can't pull your heart muscle like other muscles. While you can increase your heart rate, you can't voluntarily overload your heart the way you can with other muscles. However, extreme long-term endurance exercise can damage your heart. It can cause scarring and increase risks of heart attacks. If you have any symptoms, or are at risk of heart problems, you should check with a doctor before starting or changing your exercise routine. **AE**

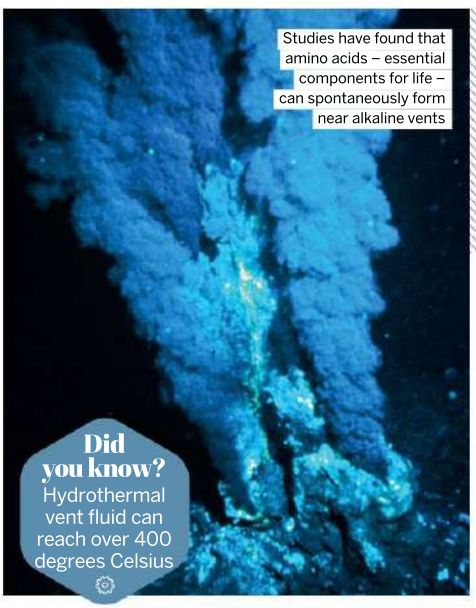
Exercise won't pull your heart muscles, but extreme exercise might damage it

WHAT DID PEOPLE THINK STARS WERE IN ANCIENT TIMES?

George Harmon

The Egyptians believed that the pharaohs became twinkling stars after they died, while the ancient Babylonians thought that the Earth was a flat disc surrounded by water, with the stars hanging above them. These 'lights' were used to predict the future. The ancient Greeks explained their presence through wondrous myths, such as tales of the god Zeus, who transformed the daughters of Atlas the Giant into a star cluster after they committed suicide. **JE**

Elaborate stories were created by the ancient Greeks to explain the constellations of stars in the sky



Studies have found that amino acids – essential components for life – can spontaneously form near alkaline vents

Did you know? Hydrothermal vent fluid can reach over 400 degrees Celsius

Did all life on Earth start in the sea?

Naseem Ware

Scientists are divided into two main camps on this issue: those who believe life originated in deep-sea hydrothermal vents, and those who think it started on land. One argument against the deep-sea vent hypothesis is that all the macromolecules in living things – DNA, proteins, lipids and so on – form through condensation reactions, which need conditions that fluctuate between wet and dry. But those on team vent say absorbent minerals around the vents could have provided a kind of dehydration. Then there's the wildcard theory of panspermia: that life began in space. It's not likely that there will be a consensus on this conundrum any time soon. **VW**

WHO CREATED THE IDEA OF CHAIRS?

Josh Harman

The four-legged chair has been around for thousands of years, and possibly even longer than that. Exactly who invented the first chair isn't known, though the early ancient Egyptians used elaborate chairs as thrones for their pharaohs over 5,000 years ago. **BB**

WHAT IS THE OLDEST PLANET?

@sammy.glanfield

The Solar System's oldest planet is Jupiter, with an age of 4.6 billion years. But some exoplanets are much older, like PSR B1620-26 b, which is 13 billion years old. **AM**

If a submarine breaks down underwater, how does it surface?

Zayn Dawson

One of the most important things in a submarine is its supply of compressed air. This can blow water out of the submarine's ballast tanks so it floats rather than sinks. If the sub can't do that, it's stuck. But even then submariners can escape in inflatable full-body waterproof suits. **AE**

A submarine being transported

© Getty / NASA / Alamy

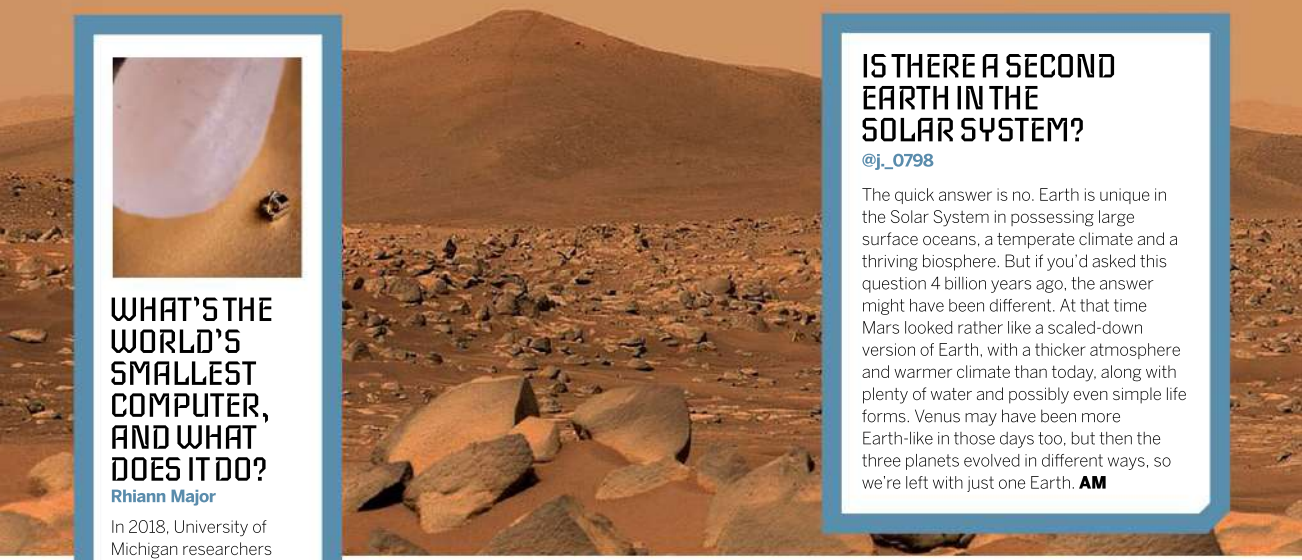
Signs of mineral deficiency in trees include yellow or sparse leaves, slow growth and wilting

Does a tree need vitamins and minerals?

Asha Higgs

Every living thing needs nutrients to grow and stay healthy. Trees require a combination of macro- and micronutrients, all of which they absorb from the soil. The key mineral elements for tree health are nitrogen, a key component of chlorophyll – essential for photosynthesis – phosphorus for root growth and the production of flowers, fruit and seeds and potassium for healthy fruit and protection from sickness. Other important nutrients include calcium, magnesium, sulphur, boron, iron and zinc. **VW**

SEND YOUR QUESTIONS TO: HOW IT WORKS MAGAZINE @HOWITWORKSMAG @HOWITWORKS@FUTURENET.COM HOWITWORKSMAG



Although Mars looks dead today, it originally had a more Earth-like atmosphere and flowing water

IS THERE A SECOND EARTH IN THE SOLAR SYSTEM?

@j._0798

The quick answer is no. Earth is unique in the Solar System in possessing large surface oceans, a temperate climate and a thriving biosphere. But if you'd asked this question 4 billion years ago, the answer might have been different. At that time Mars looked rather like a scaled-down version of Earth, with a thicker atmosphere and warmer climate than today, along with plenty of water and possibly even simple life forms. Venus may have been more Earth-like in those days too, but then the three planets evolved in different ways, so we're left with just one Earth. **AM**

WHAT'S THE WORLD'S SMALLEST COMPUTER, AND WHAT DOES IT DO?

Rhiann Major

In 2018, University of Michigan researchers made a computer smaller than a grain of rice. The 0.3 by 0.3 by 0.3 millimetre gadget is designed to be a precision temperature sensor. **AE**

WHY CAN RATS LIVE IN SEWERS AND NOT GET ILL?

Tanya Cook

Studies have shown that wild rodents have healthier immune systems than their domestic relatives. From birth they're exposed to dirt and germs, so their bodies build up strong defences. **VW**

Scientists use a thermostatic cycler to create samples for further testing

What machines are used to identify DNA in a forensic laboratory?

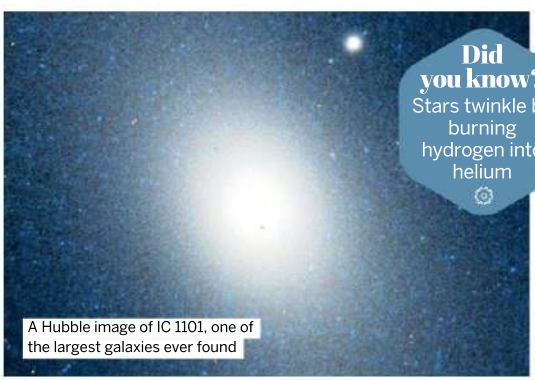
Joe Jacobs

A thermostatic cycler can separate and amplify the sample, creating copies. This is useful if the sample is small or has deteriorated. A DNA analyser is used to match samples by comparing nucleotide sequences. This can be used to show the likelihood that a suspect was present at a crime scene or if they were in contact with evidence. A polymerase chain reaction machine allows multiple experiments to be carried out on a single sample simultaneously. **JE**

IS THERE AN UPPER AND LOWER LIMIT TO THE SIZE OF GALAXIES?

Andreas Spence

Theory places firm upper and lower limits on the size of a star, but as far as we know there are no equivalent limits on galaxies. These vary enormously in size, from dwarf galaxies like Segue 2, which at 550,000 solar masses is smaller than many star clusters inside our own galaxy, to supergiants like IC 1101, which contains a hundred trillion stars – at least 200 times as many as the Milky Way. **AM**



Did you know? Stars twinkle by burning hydrogen into helium

A Hubble image of IC 1101, one of the largest galaxies ever found

© Getty / NASA / University of Michigan

THE LIBRARY

The latest book releases for curious minds

GUINNESS WORLD RECORDS 2022

THE ANNUAL THAT NEEDS NO INTRODUCTION

AUTHOR **VARIOUS**
PUBLISHER **GUINNESS WORLD RECORDS LIMITED**
ILLUSTRATOR **ROD HUNT**
PRICE **£20 / $28.95**
RELEASE **OUT NOW**

Let's start with a bit of history: *Guinness World Records* was conceived over 60 years ago in 1954 after the then-managing director of the Guinness Brewery, Hugh Beaver, had a heated debate with the hosts of a shooting party over what the fastest game bird in Europe was. Despite poring through reference books, they couldn't settle it. This inspired Beaver to put together a book that would help settle arguments in pubs, and with the help of experts, 1,000 copies were printed and given away to public houses all over the country with the aim of promoting Guinness.

But it was so popular that people wanted to buy it; it became a bestseller over Christmas 1955, and 67 years later, with millions of copies sold all over the world, we've arrived at the 2022 hardback edition - the environmental edition, which sports an incredibly detailed isometric scene on the cover by Rod Hunt. *Guinness World Records* has chosen to spotlight environmental issues this year not just because it's a hot-button topic, but it also lends itself to all shades of fascinating world records. From silly stuff like most public votes to name a research vessel, which was awarded to the now-legendary Boaty McBoatface with 124,109 votes, to cool ecological facts like the largest underground animal city – that goes to a nest of Brazilian termites that excavated the equivalent volume of 4,000 Great Pyramids of Giza. And tragic environmental records, like the largest marine oil spill: the 779 million litres of crude oil that spilled in the Gulf of Mexico following the infamous Deepwater Horizon drilling rig explosion in 2010.

There's a glossary in the back in case there's a specific record you need to look up that would resolve any pub argument you might have, and also a 'Where's Wadlow', where the reader can look for the tiny illustration of record-breaking tall man Robert Wadlow between the images on each page. Any similarity between this and Martin Handford's illustrated series of children's books is entirely coincidental. All gimmicks aside, with incredible records cover-to-cover, *Guinness World Records 2022* is no less a fun book to get sucked into than it was all those years ago.

Beaver put together a book that would help settle arguments in pubs

FROM SHORE TO OCEAN FLOOR

THE HUMAN JOURNEY TO THE DEEPEST REACHES

AUTHOR **GILL ARBUTHNOTT**
ILLUSTRATOR **CHRIS NIELSEN**
PUBLISHER **BIG PICTURE PRESS**
PRICE **£16.99 (APPROX. $23.50)**
RELEASE **OUT NOW**

Humans have explored the marine world from the oldest known boat in 8000 BCE to modern-day expeditions to the Challenger Deep, 11,000 metres underwater. At the start of this book, the reader is placed in the position of people who lived before boats. Over 65,000 years ago, without the ocean knowledge scientists hold today, flimsy rafts were made from bamboo and tree trunks and set out to scout the seas. Monsters, gods and goddesses were imagined to explain the unpredictability of the sea's movements and surprising characteristics such as its extreme salinity.

From Shore to Ocean Floor recalls the investigations and experiments that provided us with a better picture of the seas. Nielsen presents engaging illustrations to immerse the reader in each wonder of the deep. Scientific diagrams explain the movements of currents and tides, the physics behind submarines and the geography of underwater volcanoes.

This book is filled with cartoon accounts of historic expeditions and artistic depictions of some of the most mesmerising ocean life. Informative annotations focus both on ancient and recent history, as well as future solutions for protecting our oceans. Its captivating and visual style is ideal for children who want to learn about the relationship between humans and the ocean.

RUTHERFORD AND FRY'S COMPLETE GUIDE TO ABSOLUTELY EVERYTHING

THE ABRIDGED STORY OF THE ENTIRE UNIVERSE

AUTHOR **ADAM RUTHERFORD AND HANNAH FRY**
PUBLISHER **BANTAM PRESS**
PRICE **£16.99 (APPROX. $23.50)**
RELEASE **7 OCTOBER**

Can one book explain everything in the universe? The story of the universe by BBC Radio 4's Dr Adam Rutherford and Dr Hannah Fry certainly attempts to cover some of the most interesting topics. How did trial and error create life? Why do barnacles act like passports to help scientists track marine animals? And why isn't anything perfectly round? Although each new section can catch you by surprise as your thoughts are taken onto a new tangent, they are expertly interlinked. More importantly, every section leaves the reader with a better understanding of an aspect of the universe and why it makes a vital addition to the guide. Whether you're reading about the origin of Earth or the control of your own personal thoughts, the authors carry their explanations with clarity and humour.

As Rutherford and Fry explain, our lives are lived forwards, but understood backwards, and this book is the perfect way to perform the latter. For **How It Works** readers who are always looking for answers about the world around them – whether it's something you've been pondering for a while or a fact you didn't know you needed – this book is sure to bring you answers.

SNOOZEFEST

THE SURPRISING SCIENCE OF SLEEP

AUTHOR **TANYA LLOYD KYI**
ILLUSTRATOR **VALÉRY GOULET**
PUBLISHER **KIDS CAN PRESS**
PRICE **£14.99 / $19.61**
RELEASE **OUT NOW**

From brain biology to bedtime behaviours, if you're looking for explanations for your unconscious antics, then this is a must-read. This book takes the reader on a journey through the evolution of the research of sleep while maintaining an engaging and light-hearted narrative. This book is a perfect example of excellent science communication, as the author translates complex scientific studies to a mass audience with ease.

Snoozefest is structured in such a way that the reader jumps from one study or scientific discovery to the next throughout history, exploring not only the function of sleep, but also what dreams mean and advice on how to improve your sleep. There are also many fascinating sidebars and information boxes that run along with the main text for extra insight into the science of sleep. Don't let the vibrant illustrations deceive you; although this book may appear to be written for a teen audience, its content will provide surprisingly useful information for all ages to enjoy.

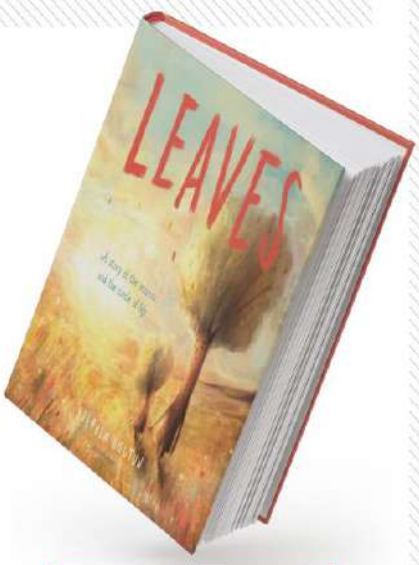
LEAVES

A STORY OF THE SEASONS AND THE CIRCLE OF LIFE

AUTHOR **STEPHEN HOGTUN**
PUBLISHER **BLOOMSBURY CHILDREN'S**
PRICE **£12.99 / £27.12**
RELEASE **OUT NOW**

When a young sapling seeks the guidance of a neighbouring wise tree, the pair set off on a journey to discover what it means to be a tree and how the seasons change their leaves. It's a sweet story for children to enjoy and discover the life of trees and the yearly cycle of change they experience. This book also teaches its young readers other important life lessons, such as resistance, compassion and appreciation for the natural world.

The book's illustrations, also created by the author, bring the story of *Leaves* to life. Their vibrancy and style help to drive the seasonal changes of the story's narrative as it moves from warm life-filled spring to the dark bareness of winter. It's the perfect example of a great bedtime story that not only entertains, but also educates.



What it means to be a tree and how the seasons change their leaves

BRAIN GYM

Give your brain a puzzle workout

Sudoku

Complete the grid so that each row, column and 3x3 box contains the numbers 1 to 9

EASY

6	1	7			5		2	
	9				8			
			6	2	3	7	1	9
1		3		7		9	4	
				6	4	1		8
	7			5		6		2
4	8				7			
7	5		2				6	4
2	3	9	1			5		7

MEDIUM

			8				7	
8	3			6	1		9	
		6				4		
3	9							5
	6	7	4		3	2	8	1
4		2	5					
	1							
				2				7
7	2	5	6	4	8	9		3

HARD

	7	3	4	9				
								1
5	6			7		9		
	2	4	9			1		3
					1			
								9
				1		6	7	
	4	1						
		9	3		4	2		5

Wordsearch

Find the following words

PREGNANT
HYDROGEN
MARS
KEYBOARD
ARK
INDUS
THEORY
SODIUM
CORAL
SOLAR
CLIMATE
GOOGLE

P	R	E	G	N	A	N	T	O	L	T	N	P	I	K
K	M	A	N	S	E	L	T	R	A	E	O	R	F	S
E	S	O	L	A	R	P	U	V	G	W	A	I	S	O
Y	A	K	R	I	N	W	B	O	M	N	T	N	O	D
D	G	T	H	E	N	U	R	P	L	F	Q	D	A	I
A	O	K	E	H	R	D	J	G	O	U	N	U	T	U
O	O	B	L	S	Y	I	L	C	P	O	D	S	C	M
E	G	T	A	H	E	Y	E	U	O	L	F	A	J	H
H	L	T	E	N	E	T	E	N	B	R	I	N	T	U
K	E	Y	B	O	A	R	D	M	E	L	A	D	O	R
F	O	G	H	D	U	I	R	A	I	V	O	L	Y	M
J	E	A	Z	E	S	X	C	L	I	M	A	T	E	F
E	U	R	S	A	R	O	O	G	R	A	L	B	I	D
G	Y	N	T	D	A	R	K	L	A	X	B	H	C	P
N	Z	P	A	T	M	K	E	Q	Y	R	O	E	H	T

What is it?

Hint: This insect is named after a mythological creature...

A

Spot the difference

See if you can find all six changes between the images below

Answers

Find the solutions to last issue's puzzle pages

Q1 HERB
Q2 9,137
Q3 SAMURAI
Q4 RED BLOOD CELLS
Q5 5,000 YEARS
Q6 RANDOM ACCESS MEMORY

What is it?

A FERN

Spot the difference

QUICKFIRE QUESTIONS

Q1 Which Anglo-Saxon king died in battle in 1066?
- William the Conqueror
- Edward the Confessor
- Harald Hardrada
- Harold II

Q2 What wavelength will the James Webb Space Telescope observe the universe in?
- Infrared
- Microwave
- X-ray
- Ultraviolet

Q3 Approximately how many Earth's would fit into Jupiter?
- 1.3
- 13
- 130
- 1,300

Q4 In computing, what does BIOS stand for?
- Bad Input Operating System
- Bit Index Organised System
- Big Isolated Order System
- Basic Input/Output System

Q5 In what year did Edward Jenner first trial the smallpox vaccine?
- 1666
- 1701
- 1796
- 1812

Q6 A walrus can weigh up to:
- 500 kilograms
- 1,000 kilograms
- 1,500 kilograms
- 2,000 kilograms

© Getty

MAKE GLASS INVISIBLE

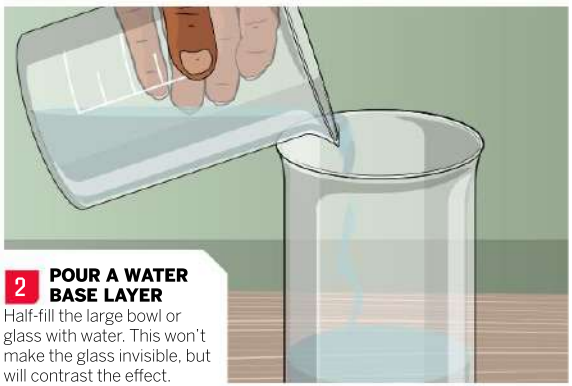
This vanishing act uses the refractive powers of vegetable oil

KIT LIST

- A Pyrex glass, bowl or beaker
- A smaller Pyrex glass or test tube
- Water
- Vegetable oil

1 GATHER YOUR EQUIPMENT

Make sure you have enough water and oil to fill your glass or bowl. The test tube or smaller glass needs to fit easily inside the larger one, be clean and scratch-free.

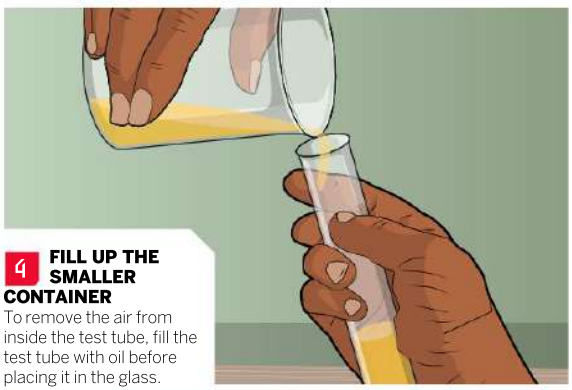


2 POUR A WATER BASE LAYER

Half-fill the large bowl or glass with water. This won't make the glass invisible, but will contrast the effect.

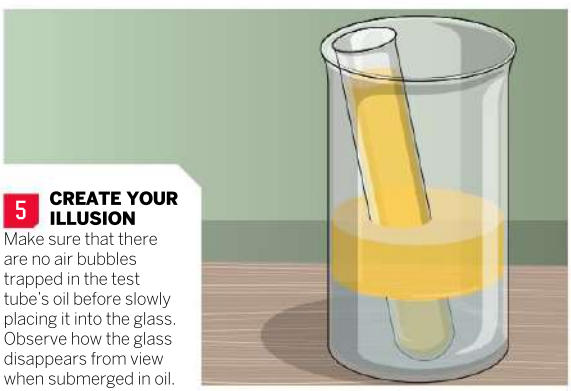
3 ADD SOME OIL

Pour your vegetable oil in, almost filling the remaining space in the glass. As it is less dense than the water it will settle on top, providing a 50/50 split.



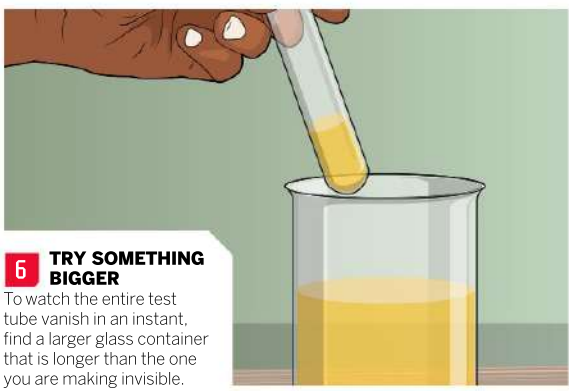
4 FILL UP THE SMALLER CONTAINER

To remove the air from inside the test tube, fill the test tube with oil before placing it in the glass.



5 CREATE YOUR ILLUSION

Make sure that there are no air bubbles trapped in the test tube's oil before slowly placing it into the glass. Observe how the glass disappears from view when submerged in oil.



6 TRY SOMETHING BIGGER

To watch the entire test tube vanish in an instant, find a larger glass container that is longer than the one you are making invisible.

NEXT ISSUE
HOW TO TURN A PENNY GREEN

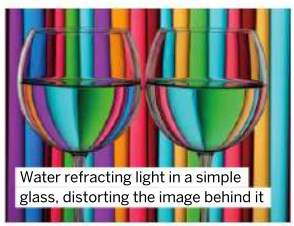
DON'T DO IT ALONE!
If you're under 16, make sure you have an adult with you

7 NOW YOU SEE IT...
This time, place an empty test tube into the oil, but keep its opening above the surface. You will notice that the air inside keeps the tube visible.

8 ...NOW YOU DON'T
Submerge the top of the test tube into the oil so that it begins to fill. As you do this, watch from the side as the oil gets to work. The glass should vanish quickly, from the bottom up.

SUMMARY

This science trick works due to the oil and glass having very similar refractive indices. When light hits an object, it has to move from one medium to another. This changes the speed of the light, and usually results in it travelling in a new direction. The angle that the light alters to is known as the refractive index, and this can be different depending on the material. On the surfaces of the glass placed in water, the different refractive indices bend the light, allowing it to return to our eyes. This is what allows us to see the object. However, in the oil the light continues to travel through the glass without reflecting or refracting, making it appear invisible.



Water refracting light in a simple glass, distorting the image behind it

Had a go? Let us know!

If you've tried out any of our experiments – or conducted some of your own – let us know! Share your photos or videos with us on social media

DISCLAIMER
Neither Future Publishing nor its employees can accept any liability for any adverse effects experienced during the course of carrying out these projects or at any time after. Always take care when handling potentially hazardous equipment or when working with electronics, and follow the manufacturer's instructions.

© Alamy / Illustrations by Ed Crooks

INBOX
Speak your mind

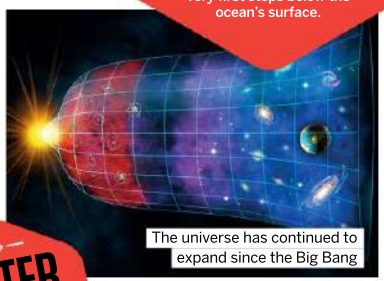
WIN!
AN AMAZING PRIZE FOR LETTER OF THE MONTH

FROM SHORE TO OCEAN FLOOR

Marvel at incredible scientific discoveries, be dazzled by some of the most exciting new species and admire the incredible people who took the very first steps below the ocean's surface.

UNKNOWN UNIVERSE

Dear **HIW**,
Could there be any possibility of life made out of dark matter or any other matter in the universe? Could there be life in 95 per cent of the universe which is unknown?
Una Ding



The universe has continued to expand since the Big Bang

LETTER of the MONTH

As you rightly state, the majority of the universe is unknown, and many speculate that for life to have arisen in the tiny percentage that we know of, it's likely to have also occurred elsewhere. Dark energy makes up around 68 per cent of the universe, while around 27 per cent is dark matter. This differs immensely from the observable universe, as it does not form in clouds. The majority of this invisible dark matter doesn't interact with anything, meaning life would be unable to form. However, a small amount might be able to host life. Scientists group all types of dark matter under one name, but that doesn't mean that all dark matter is the same. There may be a variety of dark matter particles, combining to form dark galaxies and maybe even some form of dark life. But while it remains 'dark', any answers remain speculation.

SMOOTHIE NUTRITION

Dear **HIW**,
Today I bought a smoothie which told me on the packaging how many of each fruit and vegetable were inside. It seemed like there were so many pieces of fruit inside, but the bottle said it only counted as one of my five-a-day. How could the multiple strawberries, bananas, mangoes and so on not count as more?
Carol S

Blending whole fruits and vegetables retains their nutrients but releases more sugars

This is likely to have stumped a few smoothie drinkers, as the information on packaging can be contradictory. Bottled smoothies often list the ingredients to show off how many healthy foods are packed inside. However, the recommended target of five portions of fruit and vegetables a day is limited for smoothies and juices due to their high sugar content. The British Government's health advice doesn't allow smoothie companies to claim more than one-fifth of the five-a-day target. This is to encourage consumers not to drink too much sugary juice when striving to meet it. Juicing fruit and vegetables releases more of their sugars, so we're advised not to have too many of these sugary products in one day. It is recommended that you only consume 150ml of smoothie, and that amount should count as just one portion of fruit or vegetables a day.

THE SCIENCE OF MOLES

Dear **HIW**,
Why do we grow moles all over our bodies? Does the number of moles affect our health?
Vanessa Chen

Moles are very common and usually present no health concerns. But they should be monitored for any unusual sizes or rapid growth.

A mole is created when skin cells called melanocytes grow in clusters. These cells are responsible for the colouration of your skin, and when they grow together it makes the skin darker in patches. As these are random clusters of cells, they can occur anywhere on the body, but they are most common in areas exposed to the Sun.

Moles are usually harmless, but on rare occasions they can become cancerous. It is recommended that you consult a doctor if you notice any changes in moles or if you have more than 50 on your body.

Adults usually have between ten and 40 moles

NEXT ISSUE ISSUE 157 ON SALE 28 OCT 2021

Available in print from all good newsagents and **magazinesdirect.com**, or as a digital edition for iOS and Android. To enjoy savings on the RRP and to make sure you never miss an issue, check out our subscription offers on pages 18 (UK) and 69 (US).

CURIOUS ABOUT COCKROACHES

Dear **HIW**,
Do cockroaches ever get indigestion?
Stephen Conn

Although we don't know the exact feelings of a cockroach to understand when their digestive system irritates them, there is a lot we can deduce from their anatomy. A cockroach digests food in a similar way to humans, as food is broken down by enzymes, but the shape and composition of their digestive tract is different to ours. We experience indigestion when the acid in our stomach irritates the lining of the stomach and throat. The fluid in a human stomach is acidic, with a pH between 1.5 and 3.5. Cockroaches, on the other hand, hold food in an area of their digestive system that has a pH level between 5.9 and 9.0. This covers the neutral area of the pH scale, between acidic and alkaline. As high acidity is crucial to the experience of indigestion, it's unlikely that cockroaches will experience this same feeling.

Jupiter's moon Europa has an icy surface

WATER IN SPACE

Dear **HIW**,
We're told Mars and the Moon had water but it disappeared into space. Why do the moons around other planets, and comets, have ice, as surely it too would evaporate?
Ralph Varney in Edmonton AB

Some bodies are exposed to much less ultraviolet radiation, responsible for breaking up water molecules and freeing hydrogen and oxygen. As gas is not very dense, it's less affected by gravity and likely to escape. Other conditions play a part, too. Dust storms are thought to have swept water molecules up into the atmosphere of Mars, where they could escape more easily.

WE ASKED YOU

This month on social media we asked you: What is your favourite James Bond gadget of all time?

@SAMMY_GLANFIELD
Not really a gadget but I love his Aston Martin

@JONESY_RHYS06
The DB5

@GRANT_SHELDON
Got to be the flamethrower bagpipes

@BRUCEWAYNE00051
His watch

@FKALENSKYY
His sick car

@AESTHETICALLY_AJ
The X-ray glasses

© Getty / Alamy; The Hollywood Archive / NASA / JPL-Caltech/SETI Institute

HOW IT WORKS

Future PLC Quay House, The Ambury, Bath, BA1 1UA

Editorial
Editor **Ben Biggs**
Senior Art Editor **Duncan Crook**
Production Editor **Nikole Robinson**
Research Editor **Charles Ginger**
Staff Writer **Scott Dutfield**
Staff Writer **Ailsa Harvey**
Editor-in-Chief **Gemma Lavender**

Contributors
Andrew May, Andy Extance, Jo Elphick, Mark Smith, James Horton, Victoria Williams

Cover images
Getty, United Artists, Alamy, Gravity Industries, US Navy

Photography
Alamy, Getty Images, NASA, Science Photo Library, Shutterstock, Wikimedia
All copyrights and trademarks are recognised and respected

Advertising
Media packs are available on request
Account Manager **Garry Brookes**
garry.brookes@futurenet.com
0330 390 6637
Advertising Director **Matt Johnston**
matthew.johnston@futurenet.com
07974 408083

International Licensing
How It Works is available for licensing and syndication. To find out more, contact us at **licensing@futurenet.com** or view our available content at **www.futurecontenthub.com**.
Head of Print Licensing Rachel Shaw

Subscriptions
Enquiries **help@magazinesdirect.com**
UK orderline & enquiries **0330 333 1113**
Overseas order line & enquiries **+44 (0)330 333 1113**
Online orders & enquiries **www.magazinesdirect.com**
CRM Director **Louise Dudfield**

Circulation
Head of Newstrade **Tim Mathers**

Production
Head of Production **Mark Constance**
Production Project Manager **Clare Scott**
Senior Advertising Production Manager **Joanne Crosby**
Digital Editions Controller **Jason Hudson**
Production Coordinator **Stephen Turner**

Management
Managing Director **Sarah Rafati Howard**
SVP Magazines **Angela O'Farrell**
Commercial Finance Director **Dan Jotcham**
Head of Art & Design **Greg Whittaker**
Chief Growth Officer **Claire MacLellan**

Printed by William Gibbons & Sons Limited
26 Planetary Road, Willenhall, Wolverhampton, West Midlands, WV13 3XB

Distributed by Marketforce, 5 Churchill Place, Canary Wharf, London, E14 5HU
www.marketforce.co.uk
Tel: 0203 787 9001

ISSN 2041-7322

All contents © 2021 Future Publishing Limited or published under licence. All rights reserved. No part of this magazine may be used, stored, transmitted or reproduced in any way without the prior written permission of the publisher. Future Publishing Limited (company number 2008885) is registered in England and Wales. Registered office: Quay House, The Ambury, Bath, BA1 1UA. All information contained in this publication is for information only and is, as far as we are aware, correct at the time of going to press. Future cannot accept any responsibility for errors or inaccuracies in such information. You are advised to contact manufacturers and retailers directly with regard to the price of products/services referred to in this publication. Apps and websites mentioned in this publication are not under our control. We are not responsible for their contents or any other changes or updates to them. This magazine is fully independent and not affiliated in any way with the companies mentioned herein.

If you submit material to us, you warrant that you own the material and/or have the necessary rights/permissions to supply the material and you automatically grant Future and its licensees a licence to publish your submission in whole or in part in any/all issues and/or editions of publications, in any format published worldwide and on associated websites, social media channels and associated products. Any material you submit is sent at your own risk and, although every care is taken, neither Future nor its employees, agents, subcontractors or licensees shall be liable for loss or damage. We assume all unsolicited material is for publication unless otherwise stated, and reserve the right to edit, amend, adapt all submissions.

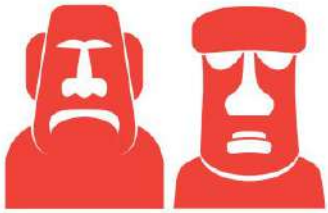
We are committed to only using magazine paper which is derived from responsibly managed, certified forestry and chlorine-free manufacture. The paper in this magazine was sourced and produced from sustainable managed forests, conforming to strict environmental and socioeconomic standards. The manufacturing paper mill holds full FSC (Forest Stewardship Council) certification and accreditation.

IPSO Regulated

Widely Recycled

FAST FACTS

Amazing trivia that will blow your mind



75,000 MILES

You'll walk the equivalent of three times around the world in your lifetime

2.8 MILLIMETRES

The stirrup in your ear is the smallest bone in your body – as long as a small ant

THERE ARE JUST UNDER 900 STONE HEADS CALLED MOAI ON EASTER ISLAND

1 MILLION CUBIC METRES

In an average lifetime, the human heart pumps enough blood to fill three supertankers

1 TRILLION

The human nose can detect a huge number of different smells

1.3 million Earths could fit inside the Sun

32.8 MILLION SQUARE MILES

The monarch of England legally owns one-sixth of the land on Earth

14 miles

The highest known mountain isn't Everest – it's on the asteroid Vesta

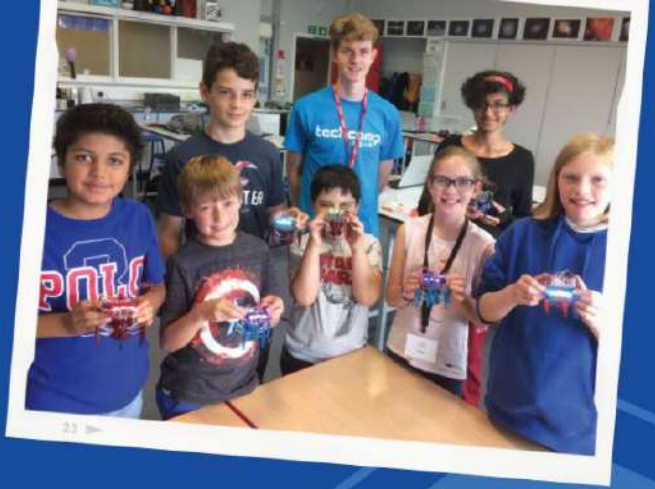
DIAMONDS CAN BE MADE FROM PEANUT BUTTER UNDER HIGH PRESSURE

12 HOURS

The time it takes for your body to fully digest a meal

200 LITRES

An adult elephant needs to drink around 2.5 bathtubs of water a day



Covid-safe Tech Camps

techcamp.org.uk

Hard year for the KIDS?

Send them on the ultimate Tech staycation at our Covid-safe camps

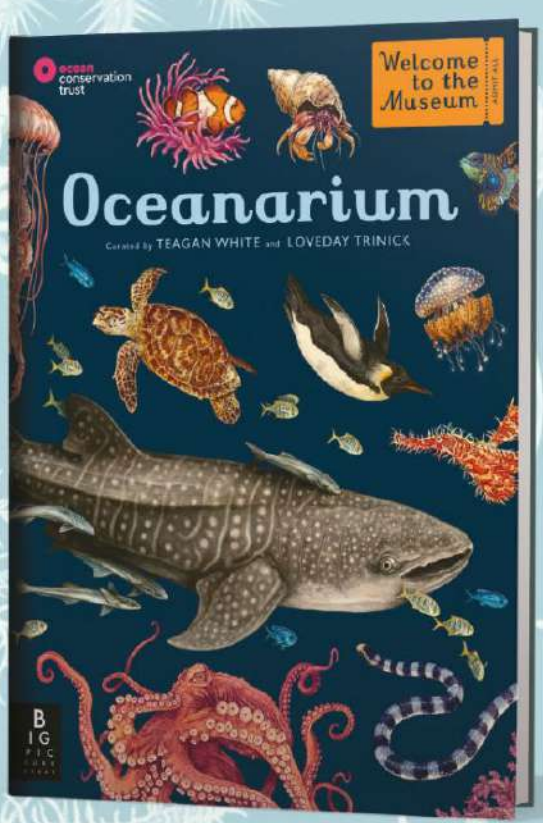
- Residential week-long camps in single en-suite rooms
- Non-residential options in London, Abingdon & Winchester
- 100% cancellation refund

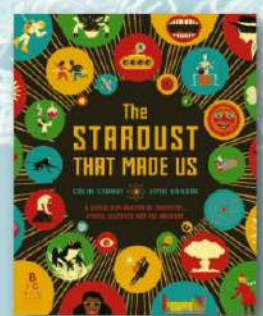
Build your Own...

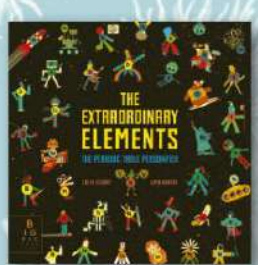
- 3D GAMES
- RACING DRONES
- GAME CONSOLES
- FIGHTING ROBOTS
- HIGH-SPEED CARS
- 3D PRINTERS

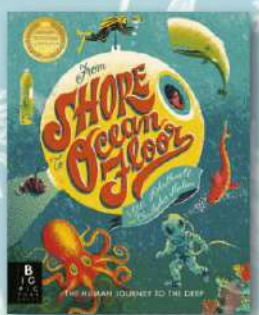
Reserve Today
www.techcamp.org.uk
0118 380 5678

Gift knowledge this Christmas









Beautiful non-fiction books for every age

BIG PICTURE PRESS

Available from Waterstones